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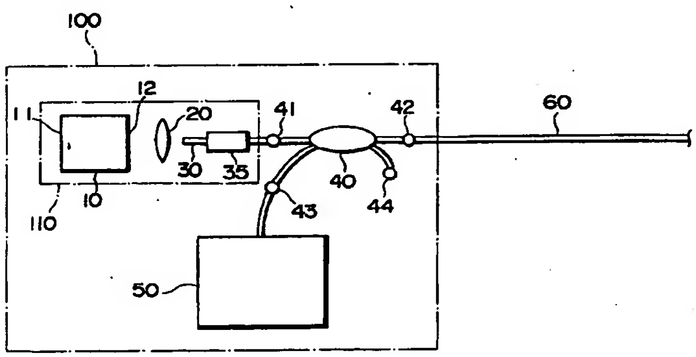
(54) Laser light source apparatus, OTDR apparatus, and optical communication line inspection system

(57) The pulse laser light source apparatus in the OTDR apparatus of present invention comprises an optical waveguide which receives and guides the light emitted from the first light-emitting end face, wherein the optical waveguide comprises a reflecting area which selectively reflects a part of light emitted from a light-emitting end face of a semiconductor light-emitting device, a core of the reflecting area comprises a first diffraction grating which is disposed in a first area and whose refractive index periodically changes along an optical-axis direction, the first diffraction grating selectively reflects, of the light emitted from the light-emitting end face of the semiconductor light-emitting device, a part of the light within a first wavelength range. And the diffraction grating is one of denvices which constitute a laser resonator.

Fig. 1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a laser light source apparatus for generating laser light having a narrow wavelength range, and an OTDR (Optical Time-Domain Reflectometry) apparatus for detecting backscattering light of an optical fiber to be measured and, based on the time characteristic of its intensity, measuring a characteristic at each point of the optical fiber in a particular wavelength of light using this laser light source apparatus, and an optical communication line inspection system for perfoming OTDR tests.

Related Background Art

Conventionally, OTDR tests have been widely used for measuring loss of optical fibers and so on. In the OTDR tests, by way of an optical coupler or the like, pulse light from a light source is made incident on an end of a fiber to be measured; backscattering light generated at each point of the fiber is detected; and the resulting electric signal data are collected so as to measure loss characteristics and the like at each point of the fiber.

As the light source for such an OTDR test, a semiconductor laser whose longitudinal mode is of multimode has been used in general. Since such a multi-longitudinal-mode semiconductor laser has a broad oscillation wavelength width exceeding 20 nm, however, it has not been suitable for measuring characteristics of optical fibers with respect to light having a specific wavelength.

On the other hand, as an OTDR test which is suitable for measuring characteristics of optical fibers with respect to light having a specific wavelength, there has been proposed an apparatus in which a light source such as optical fiber laser having a high time-coherency is used. For example, an OTDR apparatus using an optical fiber laser as an light source is disclosed in Japanese Patent Laid-Open No. 6-13688.

When the light from the light source has a high time-coherency, "Fading Noise" is created. "Fading Noise" will be familiar to those of skill in the art.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a laser light source apparatus suitably used in an OTDR apparatus or the like and to provide an OTDR apparatus which enables accurate measurement.

Also, it is an object of the present invention to provide an optical communication line inspection system which enables a suitable OTDR test.

The laser light source apparatus of the present invention comprises: (a) a semiconductor light-emitting device which is excited by a current to effect spontaneous emission and stimulated emission; (b) a reflecting means which is disposed at a position opposed to a first light-emitting end face of the semiconductor light-emitting device by way of the semiconductor light-emitting device, and reflects light generated by the semiconductor light-emitting device so as to make thus reflected light travel through the semiconductor light-emitting device again; and (c) an optical waveguide which receives and guides the light emitted from the first light-emitting end face, wherein the optical waveguide comprises a reflecting area which selectively reflects a part of the light emitted from the first light-emitting end face of the semiconductor light-emitting device, a core of the reflecting area comprises a first diffraction grating which is disposed in a first area and whose refractive index periodically changes along an optical-axis direction, and the first diffraction grating selectively reflects, of the light emitted from the first light-emitting end face of the semiconductor light-emitting device, a part of the light within a first wavelength range; in which the reflecting means, the semiconductor light-emitting device, and the diffraction grating constitute a laser resonator.

Here, the reflecting means may be constituted by either (i) a reflectively processed end face of the semiconductor light-emitting device opposed to the first light-emitting end face or (ii) a reflector which reflects light emitted from a second light-emitting end face of the semiconductor device.

When an pumping current is supplied to the semiconductor light-emitting device in the laser light source apparatus of the present invention, spontaneously emitted light and stimulatively emitted light are generated, whereby light having a relatively broad wavelength width is emitted from the light-emitting surface thereof. When thus emitted light enters the optical waveguide and reaches the diffraction grating formed in its core, only a light component having a wavelength width whose center is the reflection wavelength (Bragg wavelength) of this diffraction grating and which is narrower than the output wavelength width of the semiconductor light-emitting device is reflected thereby with a sufficient reflectance. The reflected light enters the semiconductor light-emitting device from the light-emitting surface and, while causing stimulated emission, reaches the reflecting means, where it is reflected so as to advance in the opposite direction. Thus reflected light advances through the light-emitting device, while causing stimulated emission, and then is emitted from the light-emitting surface. Thus emitted light is reflected again by the diffraction grating. As the foregoing phenomenon is repeated, light is amplified so as to finally effect laser oscillation. Accordingly, in the semiconductor light-emitting device, only the wavelength of light which travels to-and-fro is amplified, so that the other wavelength light has a very low emission level, thereby enabling laser oscillation only at a narrow wavelength width. Thus obtained laser light is emitted from the optical waveguide.

Thus, since the laser light source apparatus of the present invention uses the diffraction grating formed in the core of the optical waveguide and the reflecting means to effect laser oscillation, it outputs laser light with a narrow wavelength width corresponding to the reflection spectrum width of the diffraction grating.

The above-mentioned laser light source apparatus is constituted by the semiconductor light-emitting device, the reflecting means, and the optical waveguide, whereby the number of parts therein is remarkably smaller than that in a light source using an optical fiber laser. Accordingly, in the laser light source apparatus of the present invention, designing of optical systems and disposition of optical parts are easy; whereby the apparatus can be easily manufactured, while a smaller size is effortlessly attained.

The laser light source apparatus of the present invention may further comprise a period changing means (also referred to as "reflection wavelength adjusting means" hereinafter) which changes grating period of change in refractive index along the optical-axis direction in the first diffraction grating.

The period changing means may be either (i) a stress (ex. corresponding to tensile force) applying means which applies a stress to a part of the optical waveguide including the first diffraction grating along the optical-axis direction or (ii) a temperature adjusting means which changes temperature at the part of the optical waveguide including the first diffraction grating.

When the laser light source apparatus of the present invention has a stress applying means, as a stress is applied to the part of the optical waveguide including the diffraction grating, the period of the diffraction grating or the like changes and, in response thereto, the reflection wavelength of the diffraction grating changes as well. As the stress applied by the stress applying means is adjusted, the reflection wavelength of the diffraction grating is regulated. Since the output wavelength of the laser light source apparatus changes in response to the reflection wavelength of the diffraction grating, the wavelength of the laser light is regulated when the stress applied by the stress applying means is adjusted.

When the laser light source apparatus of the present invention has a temperature adjusting means, as temperature around the part of the optical waveguide including the diffraction grating is changed, that part expands or contracts. As a result, the period or the like of the diffraction grating changes and, in response thereto, the reflection wavelength of the diffraction grating changes as well. When the temperature adjusting means is controlled so as to adjust temperature around the part including the diffraction grating, the reflection wavelength of the diffraction grating is regulated. Since the output wavelength of the laser light source apparatus changes in response to the reflection wavelength of the diffraction grating, the wavelength of the laser light is regulated when the temperature adjusting means is controlled.

Further, the period changing means may change grating period with time.

As the reflection wavelength range of the diffraction grating is changed with time by the period changing means, the wavelength range of the laser light output from the laser light source apparatus in response thereto also changes with time. Normally, in measurement perfomed by an OTDR apparatus, data are obtained by averaging with time. Consequently, even when the reflection wavelength width of the diffraction grating is narrow, time-coherency is sufficiently lowered.

Preferably, the period changing means changes the reflection wavelength of the diffraction grating with time in a wavelength width of about 1 nm or larger. Here, "changing the reflection wavelength of the diffraction grating with time in a wavelength width of about 1 nm or larger" refers to a case where the reflection wavelength range is changed such that, in a reflection characteristic chart of the diffraction grating in which horizontal and vertical axes respectively indicate wavelength and reflectance, when an intersection between a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the diffraction grating and the reflection spectrum of the diffraction grating is determined per time, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized becomes about 1 nm or larger.

When the reflection wavelength of the diffraction grating is changed with time in a wavelength width of about 1 nm or larger, the wavelength width of the laser light is also securely broadened to a degree by which time-coherency of the laser light is sufficiently lowered.

Also, preferably, the period changing means changes the reflection wavelength of the diffraction grating with time in a wavelength width of about 20 nm or smaller. Here, "changing the reflection wavelength of the diffraction grating with time in a wavelength width of about 20 nm or smaller" refers to a case where the reflection wavelength range is changed such that, in a reflection characteristic chart of the diffraction grating in which horizontal and vertical axes respectively indicate wavelength and reflectance, when an intersection between a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the diffraction grating and the reflection spectrum of the diffraction grating is determined per time, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized becomes about 20 nm or smaller.

In this case, the wavelength width of the laser light becomes narrower than that in the conventional multi-longitudinal-mode semiconductor laser light source.

Further preferably, the change in reflection wavelength is at least 2 nm but not greater than 10 nm.

The laser light source apparatus of the present invention may further comprise a current driving means which supplies, to the semiconductor light-emitting device, a stabilizing current having a level not lower than

a threshold current level for oscillation of the laser oscillator and a pulse current required for generating pulse laser light.

Here, the current driving means may comprise (i) a first current source for supplying the stabilizing current; (ii) a second current source for supplying the pulse current; and (iii) a current adder for adding the stabilizing current and the pulse current together.

Upon operation of the current driving means, the laser oscillating operation of the laser light source apparatus is stabilized by the stabilizing current before the current driving means supplies of the pulse current to emit the pulse laser light. Accordingly, immediately after the pulse current is supplied, the laser light source apparatus emits pulse laser light with a narrow wavelength range.

Also, the current driving means may either (i) always supply a stabilizing current having a level not lower than that of the threshold current at least except for a time during which the pulse current is supplied or (ii) supply the stabilizing current over a predetermined period of time before the pulse current is supplied.

In either case of (i) and (ii), the laser oscillating operation of the laser light source apparatus is stabilized by the stabilizing current before the current driving means supplies of the pulse current to emit the pulse laser light. Accordingly, immediately after the pulse current is supplied, the laser light source apparatus emits pulse laser light with a narrow wavelength range.

In the case of (ii), the predetermined period of time for supplying the stabilizing current is preferably a time during which light travels to-and-fro through the laser resonator for once to 200 times.

During the period of time in which the laser light travels through the laser resonator to-and-fro for any of once to 200 times, stimulated emission of the laser light is stabilized so that pulse laser light with a narrow wavelength range is emitted immediately after the pulse current is supplied.

Also, the peak current level of the pulse current is preferably at least 10 times as high as the current level of the stabilizing current.

In this case, optical intensity of the light component generated as the stabilizing current is supplied is made lower than that of the pulse laser light originally required, whereby laser light is emitted with a small S/N.

Preferably, in the laser light source apparatus, the width of the first wavelength range of the light reflected by the first diffraction grating formed in the optical waveguide is 1 nm or greater.

Here, "optical waveguide" refers to a circuit or line in which difference between refractive indices of a core and a clad is utilized to confine light into a predetermined area and transmit thus confined light therethrough, and includes optical fiber, thin-film waveguide, and the like. Also, "reflection wavelength width of the diffraction grating" herein refers to the wavelength width, in a reflection characteristic chart of the diffraction grating in which horizontal and vertical axes respectively indicate wavelength and reflectance, between intersections of a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the diffraction grating and the reflection spectrum of the diffraction grating.

Of the light emitted from the semiconductor light-emitting device, a light component which is repeatedly reflected between the reflecting means and the diffraction grating disposed in the optical waveguide is subjected to laser oscillation so as to be output from the laser light source apparatus as laser light. As this laser light has a wavelength width corresponding to the reflection wavelength width of the diffraction grating; when the latter is about 1 nm or greater, the former is broadened to a degree where time-coherency of the laser light is sufficiently lowered. Here, "wavelength width of the laser light" refers to the wavelength width, in a laser light characteristic chart in which horizontal and vertical axes respectively indicate wavelength and optical power, between intersections of a line drawn in parallel to the wavelength axis at a point which is lower than the maximum power of the laser light by 20 dB and the power spectrum of the laser light.

More preferably, the width of the first wavelength range is at least 1 nm but not greater than 20 nm.

In this case, the wavelength width of laser light becomes smaller than that attained when the conventional multi-longitudinal-mode semiconductor laser light source is used.

Further preferably, the width of the first wavelength range is at least 2 nm but not greater than 10 nm.

In the laser light source apparatus of the present invention, the first diffraction grating may be constituted by a first chirped grating in which grating period monotonously changes along the optical-axis direction.

The first chirped grating has different reflection wavelength values according to respective positions therein along the optical axis, thereby exhibiting a reflection wavelength width corresponding to the width of such a change in the reflection wavelength, i.e., difference between the minimum and maximum values of the reflection wavelength. When the grating period or the width of change in the minimum refractive index is adjusted, a chirped grating having a desired reflection wavelength width can be easily obtained, and the wavelength width of laser light is determined in response to this reflection wavelength width.

Preferably, the first chirped grating is disposed such that the grating period thereof on the semiconductor light-emitting device side becomes shorter than that on the opposite side.

When the first chirped grating is thus disposed, such a phenomenon that light which should be reflected by each part of the first chirped grating is radiated outward therefrom before being reflected is prevented from occurring, whereby laser light with a substantially uniform power over the whole reflection wavelength range can be output.

The first chirped grating may be disposed such that

reflectance in the first chirped grating monotonously increases along a direction moving away from the semiconductor light-emitting device.

In this case, since the first chirped grating has different reflectance wavelength values according to respective positions therein along the optical axis of the optical waveguide, light included in the output wavelength range of the semiconductor light-emitting device is reflected at different positions according to the wavelength thereof. The light reflected at a part of the chirped grating farther from the semiconductor light-emitting device (i.e., part where the optical path length from the semiconductor light-emitting device is longer) has an optical power further attenuated. Nevertheless, in the case where the pulse width is relatively broad, when the reflectance is made greater in a part farther from the semiconductor light-emitting device as in the case of the above-mentioned chirped grating, the optical power can be made substantially uniform regardless of the part at which the light is reflected. Consequently, laser light having a substantially uniform power over the whole reflection wavelength range can be output.

When the grating period monotonously increases along a direction moving away from the semiconductor light-emitting device, the first chirped grating may be disposed such that reflectance in the first chirped grating monotonously decreases along the direction moving away from the semiconductor light-emitting device.

When the pulse width is shortened, there is a case where an effect that injection energy can be made smaller on the long wavelength side surpasses the influence of the resonator length. In such a case, when reflectance is made to decrease as the resonator length is longer, laser light with a substantially uniform power over the whole reflection wavelength range can be output.

In the laser light source apparatus of the present invention, the reflecting area may further comprise a second diffraction grating which is formed in a second area of the core and whose refractive index periodically changes along the optical-axis direction, namely, the reflecting area may comprise a plurality of diffraction gratings, such that the reflecting area can selectively reflect, of the light emitted from the first light-emitting end face of the semiconductor light-emitting device, a part of the light within a second wavelength range.

In this case, of the light emitted from the semiconductor light-emitting device, light components which are repeatedly reflected between the reflecting means and the reflecting area comprising the above-mentioned plurality of diffraction gratings are subjected to laser oscillation so as to be output from the laser light source apparatus as laser light. Even in the case where each diffraction grating constituting the reflecting area has a narrow reflection wavelength width, and each of the light components reflected by the respective diffraction gratings and subjected to laser oscillation has a high time-coherency, these laser light components are output as being superposed on each other, thereby yielding a sufficiently low time-coherency in the output laser light.

Preferably, these diffraction gratings are disposed such that the light from the semiconductor light-emitting device successively enters the diffraction gratings from the diffraction grating having a shorter reflection wavelength. When each diffraction grating is a chirped grating, the reflection wavelength values of the respective gratings are compared with each other at each part, and then the one having a greater number of shorter reflection wavelength values is adopted as "diffraction grating having a shorter reflection wavelength."

When the diffraction gratings are thus disposed, such a phenomenon that light which should be reflected by each part of the diffraction gratings is radiated outward therefrom before being reflected is prevented from occurring, whereby laser light with a substantially uniform power over the whole wavelength range can be output from the laser light source apparatus.

Preferably, the width of the second wavelength range is 1 nm or greater.

Here, "reflection wavelength of the reflecting area" refers to, in a reflection characteristic chart of the reflecting area in which horizontal and vertical axes respectively indicate wavelength and reflectance, among intersections between a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the reflecting area and the reflection spectrum of the reflecting area, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized.

When the reflecting area has a reflection wavelength width of about 1 nm or greater, the wavelength width of the laser light is also securely broadened to a degree where time-coherency of the laser light is sufficiently lowered.

More preferably, the width of the second wavelength range is at least 1 nm but not greater than 20 nm.

Here, "reflection wavelength width of the reflecting area" is defined as mentioned above.

In this case, the wavelength width of laser light becomes smaller than that attained when the conventional multi-longitudinal-mode semiconductor laser light source is used.

Further preferably, the width of the second wavelength range is at least 2 nm but not greater than 10 nm.

The second diffraction grating may be constituted by a second chirped grating in which grating period monotonously changes along the optical-axis direction.

The reflection wavelength of the second chirped grating is different from that of the other diffraction grating. Here, "reflection wavelength is different" encompasses all the cases except for the case where the reflection wavelength values between the diffraction gratings being compared with each other totally coincide with each other at each part.

The second chirped grating has different reflection wavelength values according to respective positions therein along the optical axis, thereby exhibiting a

reflection wavelength width corresponding to the width of such a change in the reflection wavelength, i.e., difference between the minimum and maximum values of the reflection wavelength. When the grating period or the width of change in the minimum refractive index is adjusted, a chirped grating having a desired reflection wavelength width can be easily obtained, and the wavelength width of laser light is determined in response to this reflection wavelength width. Accordingly, the apparatus can be easily made so as to output laser light with a desired wavelength width.

Preferably, the second chirped grating is disposed such that the grating period thereof on the semiconductor light-emitting device side becomes shorter than that on the opposite side.

When the second chirped grating is thus disposed, such a phenomenon that light which should be reflected by each part of the second chirped grating is radiated outward therefrom before being reflected is prevented from occurring, whereby laser light with a substantially uniform power over the whole reflection wavelength range can be output.

The second chirped grating may be disposed such that reflectance in the second chirped grating monotonously increases along a direction moving away from the semiconductor light-emitting device.

In this case, since the second chirped grating has different reflectance wavelength values according to respective positions therein along the optical axis of the optical waveguide, light included in the output wavelength range of the semiconductor light-emitting device is reflected at different positions according to the wavelength thereof. The light reflected at a part of the chirped grating farther from the semiconductor light-emitting device (i.e., part where the optical path length from the semiconductor light-emitting device is longer) has an optical power further attenuated. Nevertheless, when the reflectance is made greater in a part farther from the semiconductor light-emitting device as in the case of the above-mentioned chirped grating, the optical power of the reflected light can be made substantially uniform regardless of the part at which the light is reflected.

When the second grating period monotonously increases along a direction moving away from the semiconductor light-emitting device, the second chirped grating may be disposed such that reflectance in the second chirped grating monotonously decreases along the direction moving away from the semiconductor light-emitting device.

When the pulse width is shortened, there is a case where an effect that injection energy can be made smaller on the long wavelength side surpasses the influence of the resonator length. In such a case, when reflectance is made to decrease as the resonator length is longer, laser light with a substantially uniform power over the whole reflection wavelength range can be output.

The pulse laser light source apparatus comprising the first and second diffraction gratings may be constituted either (i) such that no common area exists between the first and second areas or (ii) such that the first and second areas have a common area.

The OTDR apparatus of the present invention comprises (a) a laser light source (also referred to as "inspection light source" hereinafter) comprising a semiconductor light-emitting device which is excited by a current to effect spontaneous emission and stimulated emission; a reflecting means which is disposed at a position opposed to a first light-emitting end face of the semiconductor light-emitting device by way of the semiconductor light-emitting device, and reflects light generated by the semiconductor light-emitting device so as to make thus reflected light travel through the semiconductor light-emitting device again; and an optical waveguide which receives and guides the light emitted from the first light-emitting end face, wherein the optical waveguide comprises a reflecting area which selectively reflects a part of the light emitted from the first light-emitting end face of the semiconductor light-emitting device, a core of the reflecting area comprises a first diffraction grating which is disposed in a first area and whose refractive index periodically changes along an optical-axis direction, and the first diffraction grating selectively reflects, of the light emitted from the first light-emitting end face of the semiconductor light-emitting device, a part of the light within a first wavelength range; in which the reflecting means, the semiconductor light-emitting device, and the diffraction grating constitute a laser resonator; (b) an optical path setting device which receives, from a first terminal, the light emitted from the laser light source and sends, from a second terminal, thus received light toward an optical fiber to be measured, and also receives, from the second terminal, return light from the optical fiber and sends, from a third terminal, thus received return light; and (c) an optical measurement section which measures a wavelength distribution of intensity in the light output from the third terminal of the optical path setting device. The laser light source is used as an inspection light source.

Here, the optical path setting device may be constituted by either (i) an optical coupler or (ii) a optical directional coupler.

Also, the reflecting means may be constituted by either (i) a reflectively processed end face of the semiconductor light-emitting device opposed to the first light-emitting end face or (ii) a reflector which reflects light emitted from a second light-emitting end face of the semiconductor device.

When an pumping current is supplied to the semiconductor light-emitting device in the inspection light source in the OTDR apparatus of the present invention, spontaneously emitted light and stimulatively emitted light are generated, whereby light having a relatively wide wavelength width is emitted from the light-emitting surface thereof. When thus emitted light enters the optical waveguide and reaches the diffraction grating formed in its core, only a light component having a wavelength width whose center is the reflection wave-

length (Bragg wavelength) of this diffraction grating and which is narrower than the output wavelength width of the semiconductor light-emitting device is reflected thereby with a sufficient reflectance. The reflected light enters the semiconductor light-emitting device from the light-emitting surface and, while causing stimulated emission, reaches the light-reflecting surface, where it is reflected so as to advance in the opposite direction. Thus reflected light advances through the light-emitting device, while causing stimulated emission, and then is emitted from the light-emitting surface. Thus emitted light is reflected again by the diffraction grating. As the foregoing phenomenon is repeated, light is amplified so as to finally effect laser oscillation. Accordingly, in the semiconductor light-emitting device, only the wavelength of light which travels to-and-fro is amplified, so that the other wavelength light has a very low emission level, thereby enabling laser oscillation only at a narrow wavelength width. Thus obtained laser light is emitted from the optical waveguide. This laser light is the inspection light output from the inspection light source.

Thus, since the inspection light source in the OTDR apparatus of the present invention uses the diffraction grating formed in the core of the optical waveguide and the reflecting means to effect laser oscillation, it outputs laser light with a narrow wavelength width corresponding to the reflection spectrum width of the diffraction grating. Since this laser light with a narrow wavelength width is used as the inspection light, the OTDR apparatus of the present invention can preferably measure characteristics of an optical fiber at a specific wavelength.

The above-mentioned inspection light source is constituted by the semiconductor light-emitting device, the reflecting means, and the optical waveguide, whereby the number of parts therein is remarkably smaller than that in the conventional OTDR apparatus using an optical fiber laser as its light source. Accordingly, in the OTDR apparatus of the present invention, designing of optical systems and disposition of optical parts are easy, whereby the apparatus is easily manufactured while a smaller size is effortlessly attained.

The OTDR apparatus of the present invention may further comprise a band pass filter in an optical path between the laser light source, which is the inspection light source, and the optical fiber to be measured.

In the inspection light source in the OTDR apparatus of the present invention, one of facing mirrors is constituted by a diffraction grating formed in the optical waveguide so as to narrow the wavelength width of the oscillated laser light. Nevertheless, when the resonator length becomes large, due to its relationship to pulse width, the number of to-and-fros of light through the resonator decreases. Accordingly, though with a low power, oscillation wavelength cannot be prevented from expanding. When OTDR test is perfomed, there are cases where, in order to prevent crosstalk to a signal transmission band from occurring, such an extension of oscillation wavelength is desired to be reduced by an amount which is beyond the capacity of the diffraction grating.

In such cases, when a band pass filter is further provided in an optical path between the laser light source, which is the inspection light source, and the optical fiber to be measured, light outside of the wavelength range necessary for the OTDR apparatus can be cut off, whereby a prefeable output characteristic can be obtained.

The OTDR apparatus of the present invention may further comprise a period changing means which changes grating period of change in refractive index along the optical-axis direction in the first diffraction grating.

The period changing means may be either (i) a stress (ex. corresponding to tensile force) applying means which applies a stress to a part of the optical waveguide including the first diffraction grating along the optical-axis direction or (ii) a temperature adjusting means which changes temperature at the part of the optical waveguide including the first diffraction grating.

When the inspection light source in the OTDR apparatus of the present invention has a stress applying means, as a stress is applied to the part of the optical waveguide including the diffraction grating, the period of the diffraction grating or the like changes and, in response thereto, the reflection wavelength of the diffraction grating changes. As the stress applied by the stress applying means is adjusted, the reflection wavelength of the diffraction grating is regulated. Since the output wavelength of the inspection light source changes in response to the reflection wavelength of the diffraction grating, the wavelength of the inspection light is regulated when the stress applied by the stress applying means is adjusted.

When the inspection light source in the OTDR apparatus of the present invention has a temperature adjusting means, as temperature around the part of the optical waveguide including the diffraction grating is changed, that part expands or contracts. As a result, the period or the like of the diffraction grating changes and, in response thereto, the reflection wavelength of the diffraction grating changes. When the temperature adjusting means is controlled so as to adjust temperature around the part including the diffraction grating, the reflection wavelength of the diffraction grating is regulated. Since the output wavelength of the inspection light source changes in response to the reflection wavelength of the diffraction grating, the wavelength of the inspection light is regulated when the temperature adjusting means is controlled.

Further, the period changing means can change the grating period with time.

Of the light emitted from the semiconductor light-emitting device, a light component which is repeatedly reflected between the light-reflecting surface of the semiconductor light-emitting device and the diffraction grating disposed in the optical waveguide is subjected to laser oscillation so as to be output from the inspection

light source as inspection light. As the reflection wavelength range of the diffraction grating is changed with time by the period changing means, the wavelength range of the inspection light output from the inspection light source in response thereto also changes with time. Normally, in measurement perfomed by an OTDR apparatus, data are obtained by averaging with time. Consequently, even when the reflection wavelength width of the diffraction grating is narrow, it is possible to obtain data equivalent to those obtained with inspection light having a wavelength width which is large enough to sufficiently lower time-coherency. When such inspection eight is used, an OTDR test with suppressed fading noise can be perfomed.

Preferably, the period changing means changes the reflection wavelength of the diffraction grating with time in a wavelength width of about 1 nm or larger. Here, "changing the reflection wavelength of the diffraction grating with time in a wavelength width of about 1 nm or larger" refers to a case where the reflection wavelength range is changed such that, in a reflection characteristic chart of the diffraction grating in which horizontal and vertical axes respectively indicate wavelength and reflectance, when an intersection between a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the diffraction grating and the reflection spectrum of the diffraction grating is determined per time, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized becomes about 1 nm or greater.

When the reflection wavelength of the diffraction grating is changed with time in a wavelength width of about 1 nm or larger, the wavelength width of the inspection light is also securely broadened to a degree where time-coherency of the laser light is sufficiently lowered. As such inspection light with a low time-coherency is used, an OTDR test with suppressed fading noise can be securely perfomed.

Also, preferably, the period changing means changes the reflection wavelength of the diffraction grating with time in a wavelength width of about 20 nm or smaller. Here, "changing the reflection wavelength of the diffraction grating with time in a wavelength width of about 20 nm or smaller" refers to a case where the reflection wavelength range is changed such that, in a reflection characteristic chart of the diffraction grating in which horizontal and vertical axes respectively indicate wavelength and reflectance, when an intersection between a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the diffraction grating and the reflection spectrum of the diffraction grating is determined per time, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized becomes about 20 nm or smaller.

In this case, the wavelength width of the inspection light becomes narrower than that in the case where the conventional multi-longitudinal-mode semiconductor laser light source is used as inspection light source, whereby a characteristic of an optical fiber at a specific wavelength can be measured more preferably than that conventionally measured.

The inspection light source in the OTDR apparatus of the present invention may further comprise a current driving means which supplies, to the semiconductor light-emitting device, a stabilizing current having a level not lower than a threshold current level for oscillation of the laser oscillator and a pulse current required for generating the pulse laser light.

Here, the current driving means may comprise (i) a first current source for supplying the stabilizing current; (ii) a second current source for supplying a pulse current; and (iii) a current adder for adding the stabilizing current and the pulse current together.

The laser oscillating operation of the inspection light source is stabilized by the stabilizing current before the current driving means supplies the pulse current to emit the pulse laser light. Accordingly, immediately after the pulse current is supplied, the inspection light source emits pulse laser light (inspection light or strobe light) with a narrow wavelength range. Therefore, samples can be measured with a high accuracy.

Also, the current driving means may either (i) always supply a stabilizing current having a level not lower than that of the threshold current at least except for a time during which the pulse current is supplied or (ii) supply the stabilizing current over a predetermined period of time before the pulse current is supplied.

In either case of (i) and (ii), the laser oscillating operation of the inspection light source is stabilized by the stabilizing current before the current driving means supplies the pulse current to emit the pulse laser light. Accordingly, immediately after the pulse current is supplied, the inspection light source emits pulse laser light with a narrow wavelength range. Therefore, samples can be measured with a high accuracy.

In this case, the predetermined period of time for supplying the stabilizing current is preferably a time during which light travels to-and-fro through the laser resonator for once to 200 times.

During the period of time in which the laser light travels through the laser resonator to-and-fro for any of once to 200 times, stimulated emission of the laser light is stabilized so that pulse laser light with a narrow wavelength range is emitted immediately after the pulse current is supplied. Therefore, samples can be measured with a high accuracy.

Also, the peak current level of the pulse current is preferably at least 10 times as high as the current level of the stabilizing current.

As optical intensity of the light component generated upon supply of the stabilizing current is made lower than that of the pulse laser light originally required, laser light can be emitted with a small S/N; and as pulse laser light with a narrow wavelength range is emitted immediately after the supply of pulse current, samples can be measured with a high accuracy.

Preferably, in the OTDR apparatus supplying the stabilizing current, the optical measurement section further comprises a high pass filter which eliminates a low frequency component in input optical intensity.

In this case, the DC component in the reflected light, resulting from the fact that the strobe light contains a light component generated upon the supply of stabilizing current, is eliminated. Accordingly, information about the reflected light is substantially obtained while only the pulse laser light is used as inspection light. Therefore, samples can be measured with a high accuracy.

Preferably, in the OTDR apparatus of the present invention, the width of the first wavelength range of the light reflected by the first diffraction grating formed in the optical waveguide is 1 nm or greater.

Of the light emitted from the semiconductor light-emitting device, a light component which is repeatedly reflected between the reflecting means and the diffraction grating disposed in the optical waveguide is subjected to laser oscillation so as to be output from the inspection light source as inspection light. As this inspection light has a wavelength width corresponding to the reflection wavelength width of the diffraction grating; when the latter is about 1 nm or greater, the former is broadened to a degree where time-coherency of the laser light is sufficiently lowered. Here, "wavelength width of the laser light" refers to the wavelength width, in an inspection light characteristic chart in which horizontal and vertical axes respectively indicate wavelength and optical power, between intersections of a line drawn in parallel to the wavelength axis at a point which is lower than the maximum power of the inspection light by 20 dB and the power spectrum of the inspection light. When such inspection light with a low time-coherency is used, OTDR tests with suppressed fading noise can be perfomed.

More preferably, the width of the first wavelength range is at least 1 nm but not greater than 20 nm.

In this case, since the wavelength width of inspection light becomes smaller than that attained when the conventional multi-longitudinal-mode semiconductor laser light source is used as inspection light source, a characteristic of an optical fiber at a specific wavelength can be measured more preferably than that conventionally measured.

Further preferably, the width of the first wavelength range is at least 2 nm but not greater than 10 nm.

In the OTDR apparatus of the present invention, the first diffraction grating may be constituted by a first chirped grating in which grating period monotonously changes along the optical-axis direction.

The first chirped grating has different reflection wavelength values according to respective positions therein along the optical axis, thereby exhibiting a reflection wavelength width corresponding to the width of such a change in the reflection wavelength, i.e., difference between the minimum and maximum values of the reflection wavelength. When the grating period or the width of change in the minimum refractive index is adjusted, a chirped grating having a desired reflection wavelength width can be easily obtained, and the wavelength width of inspection light is determined in response to this reflection wavelength width. Accordingly, the OTDR apparatus comprising an inspection light source with a chirped grating can be easily made so as to output inspection light with a desired wavelength width.

Preferably, the first chirped grating is disposed such that the grating period thereof on the semiconductor light-emitting device side becomes shorter than that on the opposite side.

When the first chirped grating is thus disposed, such a phenomenon that light which should be reflected by each part of the first chirped grating is radiated outward therefrom before being reflected is prevented from occurring, whereby inspection light with a substantially uniform power over the whole reflection wavelength range is output from the inspection light source. Therefore, OTDR tests can be perfomed more preferably.

The first chirped grating may be disposed such that reflectance in the first chirped grating monotonously increases along a direction moving away from the semiconductor light-emitting device.

In this case, since the first chirped grating has different reflectance wavelength values according to respective positions along the optical axis of the optical waveguide, light included in the output wavelength range of the semiconductor light-emitting device is reflected at different positions according to the wavelength thereof. The light reflected at a part of the chirped grating farther from the semiconductor light-emitting device (i.e., part where the optical path length from the semiconductor light-emitting device is longer) has an optical power further attenuated. Nevertheless, in the case where the pulse width is relatively broad, when the reflectance is made greater in a part farther from the semiconductor light-emitting device as in the case of the above-mentioned chirped grating, the optical power can be made substantially uniform regardless of the part at which the light is reflected. Consequently, inspection light having a substantially uniform power over the whole wavelength range can be output from the inspection light source in the OTDR apparatus comprising the above-mentioned chirped grating, whereby OTDR tests can be perfomed more preferably.

When the grating period monotonously increases along a direction moving away from the semiconductor light-emitting device, the first chirped grating may be disposed such that reflectance in the first chirped grating monotonously decreases along the direction moving away from the semiconductor light-emitting device.

When the pulse width is shortened, there is a case where an effect that injection energy can be made smaller on the long wavelength side surpasses the influence of the resonator length. In such a case, when reflectance is made to decrease as the resonator length is longer, inspection light with a substantially uniform power over the whole reflection wavelength range can

be output. As a result, preferable OTDR tests can be perfomed.

In the OTDR apparatus of the present invention, the reflecting area may further comprise a second diffraction grating which is formed in a second area of the core and whose refractive index periodically changes along the optical-axis direction, namely, the reflecting area may comprise a plurality of diffraction grating, such that the reflecting area can selectively reflect, of the light emitted from the first light-emitting end face of the semiconductor light-emitting device, a part of the light within a second wavelength range.

In this case, of the light emitted from the semiconductor light-emitting device, light components which are repeatedly reflected between the reflecting means device and the reflecting area comprising the above-mentioned plurality of diffraction gratings are subjected to laser oscillation so as to be output from the laser light source apparatus as inspection light. Even in the case where each diffraction grating constituting the reflecting area has a narrow reflection wavelength width, and each of the light components reflected by the respective diffraction gratings and subjected to laser oscillation has a high time-coherency, these laser light components are output as being superposed on each other, thereby yielding a sufficiently low time-coherency in the output inspection light. Accordingly, in the OTDR apparatus of the present invention, OTDR tests can be perfomed with suppressed fading noise.

Preferably, these diffraction gratings are disposed such that the light from the semiconductor light-emitting device successively enters the diffraction gratings from the diffraction grating having a shorter reflection wavelength. When each diffraction grating is a chirped grating, the reflection wavelength values of the respective gratings are compared with each other at each part thereof, and then the one having a greater number of shorter reflection wavelength values is adopted as "diffraction grating having a shorter reflection wavelength."

When the diffraction gratings are thus disposed, such a phenomenon that light which should be reflected by each part of the diffraction gratings is radiated outward therefrom before being reflected is prevented from occurring, whereby inspection light with a substantially uniform power over the whole wavelength range can be output from the inspection light source. Accordingly, OTDR tests can be perfomed more preferably.

Preferably, the width of the second wavelength range is 1 nm or greater.

Here, "reflection wavelength of the reflecting area" refers to, in a reflection characteristic chart of the reflecting area in which horizontal and vertical axes respectively indicate wavelength and reflectance, among intersections between a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the reflecting area and the reflection spectrum of the reflecting area, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized.

When the reflecting area has a reflection wavelength width of about 1 nm or greater, the wavelength width of the inspection light is also securely broadened to a degree where time-coherency of the inspection light is sufficiently lowered. When such inspection light with a low time-coherency is used, OTDR tests with suppressed fading noise can be securely perfomed.

More preferably, the width of the second wavelength range is at least 1 nm but not greater than 20 nm.

Here, "reflection wavelength width of the reflecting area" is defined as mentioned above.

In this case, since the wavelength width of inspection light becomes smaller than that attained when the conventional multi-longitudinal-mode semiconductor laser light source is used as inspection light source, a characteristic of an optical fiber at a specific wavelength can be measured more preferably than that conventionally measured.

Further preferably, the width of the second wavelength range is at least 2 nm but not greater than 10 nm.

The second diffraction grating may be constituted by a second chirped grating in which grating period monotonously changes along the optical-axis direction.

The second chirped grating and the other diffraction grating have reflection wavelengths different from each other. Here, "diffraction gratings have different reflection wavelengths" encompasses all the cases except for the case where the reflection wavelength values between the diffraction gratings being compared with each other totally coincide with each other at each part thereof.

The second chirped grating has different reflection wavelength values according to respective positions therein along the optical axis, thereby exhibiting a reflection wavelength width corresponding to the width of such a change in the reflection wavelength, i.e., difference between the minimum and maximum values of the reflection wavelength. When the grating period or the width of change in the minimum refractive index is adjusted, a chirped grating having a desired reflection wavelength width can be easily obtained, and the wavelength width of inspection light is determined in response to this reflection wavelength width. Accordingly, the OTDR apparatus comprising a chirped grating can be easily made so as to output inspection light with a desired wavelength width.

Preferably, the second chirped grating is disposed such that the grating period thereof on the semiconductor light-emitting device side becomes shorter than that on the opposite side.

When the second chirped grating is thus disposed, such a phenomenon that light which should be reflected by each part of the second chirped grating is radiated outward therefrom before being reflected is prevented from occurring, whereby inspection light with a substantially uniform power over the whole reflection wavelength range can be output. Accordingly, OTDR tests can be perfomed more preferably.

The second chirped grating may be disposed such

that reflectance in the second chirped grating monotonously increases along a direction moving away from the semiconductor light-emitting device.

Since the second chirped grating has different reflectance wavelength values according to respective positions along the optical axis of the optical waveguide, light included in the output wavelength range of the semiconductor light-emitting device is reflected at different positions according to the wavelength thereof. The light reflected at a part of the chirped grating farther from the semiconductor light-emitting device (i.e., part where the optical path length from the semiconductor light-emitting device is longer) has an optical power further attenuated. Nevertheless, when the reflectance is made greater in a part farther from the semiconductor light-emitting device as in the case of the above-mentioned chirped grating, the optical power of the reflected light can be made substantially uniform regardless of the part at which the light is reflected. Accordingly, in the OTDR apparatus comprising the above-mentioned chirped grating, inspection light having a substantially uniform power over the whole reflection wavelength range can be output from the inspection light source, whereby OTDR tests can be perfomed more preferably.

When the grating period in the second diffraction grating monotonously along a direction moving away from the semiconductor light-emittimg device, the second chirped grating may be disposed such that reflectance in the second chirped grating monotonously decreases along the direction moving away from the semiconductor light-emitting device.

When the pulse width is shortened, there is a case where an effect that injection energy can be made smaller on the long wavelength side surpasses the influence of the resonator length. In such a case, when reflectance is made to decrease as the resonator length is longer, inspection light with a substantially uniform power over the whole reflection wavelength range can be output.

The OTDR apparatus in which the reflecting area of the optical waveguide comprises the first and second diffraction gratings may be constituted either (i) such that no common area exists between the first and second areas or (ii) such that the first and second areas have a common area.

The optical communication line inspection system of the present invention is an optical communication line inspection system for inspecting transmission state of an optical communication line which is transmitting signal light, and comprises (a) a light-emitting section for outputting inspection light with a wavelength in a first wavelength range; (b) an optical path setting section disposed in an optical path of the optical communication line, which optical path setting section receives the inspection light output from the light-emitting section and introduces thus received inspection light into the optical communication line, and also receives return light derived from the inspection light input from the optical communication line and outputs thus received return light to a path different from the optical communication line; (c) a waveguide type reflecting means disposed at a terminating portion of the optical communication line, which reflecting means reflects light with a wavelength in a second wavelength range including the first wavelength range and comprises a first diffraction grating in which at least refractive index of a core thereof periodically changes along an optical-axis direction; and (d) a processing section which measures a wavelength distribution of intensity in the return light output from the optical path setting section and, based on a result of the measurement, determines the transmission state of the optical communication line.

Here, the width of the first wavelength range is preferably 20 nm or smaller and, more preferably, 5 nm or smaller.

In the optical communication line inspection system of the present invention, since the waveguide type reflecting means comprises a waveguide type diffraction grating, and inspection light within a wavelength range included in the reflection wavelength of the waveguide type reflecting means is used to inspect the optical communication line, the optical communication line can be inspected while influence upon optical communications is suppressed.

When the light-emitting section outputs inspection light with a wavelength width of about 20 nm or smaller, and this inspection light is used to inspect an optical communication line; the reflection wavelength width of the waveguide type reflecting means can be sufficiently narrowed. Accordingly, the transmission loss of signal light caused by mode-mismatching and absorption of OH group is lowered, whereby the optical communication line can be inspected while influence upon optical communications is sufficiently suppressed.

In particular, when the wavelength width of the inspection light output from the light-emitting section is about 5 nm or smaller, the number of waveguide type diffraction gratings can be made very small, whereby influence of the optical communication line inspection upon optical communications can become very little.

As a light source apparatus adopted in the light-emitting section, either (i) a laser light source apparatus in accordance with the present invention or (ii) a distributed feedback type semiconductor laser can be suitably used.

The optical communication line inspection system of the present invention may further comprise a band pass filter in an optical path between the light-emitting section and the optical communication line.

The light source of the light-emitting section has a narrow wavelength width. Nevertheless, there are cases where, due to the relationship to the generated pulse width, though with a low power, oscillation wavelength cannot be prevented from expanding. When inspection is perfomed, in order to prevent crosstalk to a signal transmission band from occurring, such an extension of oscillation wavelength is desired to be reduced by an amount which beyond the capacity of the diffraction

grating.

In such a case, when a band pass filter is further provided in an optical path between the light-emitting section and the optical communication line to be measured, light outside of the wavelength range necessary for the inspection can be cut off, whereby influence upon optical communications can be securely suppressed.

The present invention will be more fully understood from the detailed description given hereinbelow and the accompanying drawings, which are given by way of illustration only and are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will be apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view showing a configuration of an OTDR apparatus in accordance with Embodiment 1;
Fig. 2 is a chart showing a wavelength spectrum of light emitted from a semiconductor laser 10;
Fig. 3 is a chart showing a reflection spectrum of a diffraction grating 35;
Fig. 4 is a chart showing an oscillation spectrum of an inspection light source 100;
Fig. 5 is a configurational view showing a main part of an OTDR apparatus according to Embodiment 2;
Fig. 6 is a configurational view showing a main part of an OTDR apparatus according to Embodiment 3;
Fig. 7 is an explanatory view showing a schematic configuration of a first example of a pulse laser light source in an OTDR apparatus in accordance with Embodiment 4;
Figs. 8 to 11 are explanatory views for explaining an operation and principle of the pulse laser light source in the first example;
Figs. 12 to 15 are explanatory views for explaining an operation and principle of a second example of the pulse laser light source in the OTDR apparatus in accordance with Embodiment 4;
Fig. 16 is an explanatory view showing a schematic configuration of a mode of realization of the OTDR apparatus in accordance with Embodiment 4;
Fig. 17 is a view showing a view showing a configuration of an OTDR apparatus in accordance with Embodiment 5;
Fig. 18 is a chart showing a reflection characteristic of the diffraction grating 35;
Fig. 19 is a characteristic chart of inspection light output from an inspection light source 1a;
Fig. 20 is a view showing a configuration of an OTDR apparatus in accordance with Embodiment 6;
Fig. 21 is a chart showing a reflection characteristic of a reflecting area 38;
Fig. 22 is a characteristic chart of inspection light output from an inspection light source 1b;
Fig. 23 is a view showing a configuration of an OTDR apparatus in accordance with Embodiment 7;
Fig. 24 is a view showing a configuration of an OTDR apparatus in accordance with Embodiment 8;
Fig. 25 is a chart showing a change in a reflection characteristic of a diffraction grating 36;
Fig. 26 is a chart showing a change in a characteristic of inspection light output from an inspection light source 1d;
Figs. 27 and 28 are configurational views respectively showing modified examples of Embodiment 1;
Fig. 29 is a view showing an overall configuration of an optical communication line inspection system in accordance with the present invention;
Fig. 30 is a view schematically showing a reflection spectrum of an optical filter and a wavelength spectrum of inspection light;
Fig. 31 is a first configurational view of a light-emitting section 310;
Fig. 32 is a second configurational view of the light-emitting section 310;
Fig. 33 is a third configurational view of the light-emitting section 310; and
Fig. 34 is a fourth configurational view of the light-emitting section 310.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following, embodiments of the present invention will be explained in detail with reference to attached drawings. In the explanation of the drawings, elements identical to each other will be referred to with marks identical to each other without their overlapping explanations being repeated. Also, sizes and ratios in the drawings do not always coincide with those explained.

(Embodiment 1)

Fig. 1 is a schematic view showing a configuration of an OTDR apparatus 100 in this embodiment. This OTDR apparatus 100 is constituted by an inspection light source 110, an optical coupler 40, and a measurement section 50.

The inspection light source 110 oscillates in a pulsing manner to emit laser light. It is constituted by a Fabry-Perot type semiconductor laser 10, a lens 20, and an optical fiber 30. It is formed as the optical fiber 30 is optically connected, by way of the lens 20, to the Fabry-Perot type semiconductor laser 10 which has been con-

ventionally used as inspection light source of an OTDR apparatus. This inspection light source 110 is similar to that disclosed in a paper of D.M. Bird et al (Electron. Lett., Vol. 30 , No. 13, pp. 1115-1116, 1994).

The Fabry-Perot type semiconductor laser 10 is a semiconductor light-emitting device constituted by a hetero-structure of InGaAsP/InP. When an operating current flows therethrough, it is excited so as to output pulse light of 1,550 nm band. On both sides of the hetero-structure, a light-reflecting surface 11 and a light-emitting surface 12 are respectively disposed. These surfaces are opposed to each other, thereby forming a Fabry-Perot laser resonator. The light-reflecting surface 11 has a high reflectance (about 80% in this embodiment), whereas the light-emitting surface 12 has a low reflectance (about 5% in this embodiment). As in the case of most Fabry-Perot type devices, the semiconductor laser 10 is a multi-longitudinal-mode laser and shows an oscillation spectrum in which output increases in response to wavelengths in the respective modes.

The lens 20 converges the light emitted from the semiconductor laser 10 so as to make it incident on the optical fiber 30, thereby coupling the semiconductor laser 10 to the optical fiber 30 in terms of optical power. As the lens 20, an ordinary optical coupling lens such as that used in optical communications can be employed.

Here, a tip of the optical fiber 30 may be processed by melting or shaving to have a lens function, thereby eliminating the lens 20 which is arranged between the semiconductor laser 10 and the optical fiber 30.

The optical fiber 30 comprises an ordinary single-mode optical fiber and a diffraction grating 35 formed at a part of its core. The refractive index of this diffraction grating 35, which is an area of the core, periodically changes between the minimum refractive index and the maximum refractive index according to positions along its optical axis. The period of this change in refractive index corresponds to the period of the diffraction grating.

It has been known in general that, when "interference of two lightwaves" technique is used to generate an interference fringe of ultraviolet rays, and an optical fiber having a core doped with GeO_2 is irradiated with thus generated interference fringe, the diffraction grating 35 can be formed. This manufacturing method is disclosed in Japanese Publication of the Translation of International Application No. 62-500052. In this method, since the effective refractive index of the core increases according to the optical intensity distribution of the interference fringe, an area where the refractive index fluctuates between the original effective refractive index of the core and the increased effective refractive index is formed. This area is the diffraction grating 35.

The diffraction grating 35 reflects light over a narrow wavelength width whose center is a predetermined reflection wavelength λ_R. This reflection wavelength λ_R is expressed as:

$$\lambda_R = 2 \cdot n \cdot \Lambda \qquad (1)$$

wherein n is the effective refractive index of the diffraction grating 35 and Λ is the period of the diffraction grating 35.

The optical coupler 40 is a kind of an optical directional coupler having four terminals, i.e., first to third terminals 41 to 43 and a resistive terminator 44. The first terminal 41 is connected to the optical fiber 30 such that the inspection light from the inspection light source 100 is incident on the optical coupler 40. To the second terminal 42, an optical fiber 60 to be measured is connected.

The inspection light incident on the optical coupler 40 is split into two light components. One of the split light components is made incident on the optical fiber 60 to be measured. Of the incident inspection light, backscattering light which has been made to advance in the opposite direction due to Rayleigh scattering at each point of the optical fiber 60 is made incident on the optical coupler 40 and then split into two. One of thus split light component is made incident on the measurement section 50.

As in the case of the conventional OTDR apparatus, an optical directional coupler such as optical circulator may be used in place of the optical coupler 40.

The measurement section 50, which measures the backscattering light of the optical fiber 60 to be measured, is connected to the third terminal 43 of the optical coupler 40. The measurement section 50, which is similar to that used in ordinary OTDR apparatuses, comprises a photodetector which detects the backscattering light and converts thus detected light into an electric signal; an amplifier for amplifying the electric signal output from the photodetector; a signal processing section which A/D-converts the signal output from the amplifier and further subjects thus converted signal to an averaging processing or the like; a CRT device connected to the signal processing section; and the like. Based on the output signal of the signal processing section, the CRT device displays the scattering light power of the optical fiber 60 with respect to the distance from a predetermined reference point to the measurement point in the optical fiber 60. As thus displayed waveform is observed, loss between two arbitrary points in the optical fiber can be determined.

The inspection light source 110 outputs laser pulse light having a wavelength width narrower than the output wavelength width of the semiconductor laser 10. The principle thereof will be explained in the following.

When an operating current flows through the Fabry-Perot type semiconductor laser 10, spontaneously emitted light is generated. As this light is repeatedly reflected between the light-reflecting surface 11 and the light-emitting surface 12 while causing stimulated emission, the light is amplified so as to finally generate laser oscillation. In this manner, the light reflected by the light-emitting surface 12 contributes to laser oscillation of the semiconductor laser 10.

Nevertheless, since the reflectance of the light-emitting surface 12 is as low as 5%, most of the sponta-

neously emitted light and stimulatively emitted light can pass through the light-emitting surface 12. Fig. 2 is a chart showing a wavelength spectrum of light emitted from the light-emitting surface 12. The emitted light has a wavelength range of about 1,540 nm to about 1,560 nm with a wavelength width of about 20 nm.

The light emitted through the light-emitting surface 12 passes through the lens 20 and then is made incident on the optical fiber 30, thereby reaching the diffraction grating 35. Fig. 3 is a chart showing a reflection spectrum of the diffraction grating 35. As indicated by Fig. 3, the reflection wavelength λ_R of the diffraction grating 35 is about 1,553.3 nm, and relatively high reflectance is exhibited over a narrow wavelength width whose center is this wavelength. Here, the reflectance with respect to the reflection wavelength is about 47%.

The light reflected by the diffraction grating 35 is made incident, by way of the lens 20, on the semiconductor laser 10 from the light-emitting surface 12, and reaches the light-reflecting surface 11 while causing stimulated emission. The light reflected by the light-reflecting surface 11 advances, while causing stimulated emission, so as to be emitted from the light-emitting surface 12 and then incident on the optical fiber 30 again. This incident light reaches the diffraction grating 35, where it is reflected again. Thus, as reflection is repeated between the diffraction grating 35 and the light-reflecting surface 11, light is amplified so as to finally generate laser oscillation. Consequently, laser light is emitted from the end face of the optical fiber 30 facing the optical coupler 40. Thus emitted laser light is the inspection laser light output from the inspection light source 110.

The light generating laser oscillation between the diffraction grating 35 and the light-reflecting surface 11 is limited to light having a wavelength which is reflected by the diffraction grating 35 with a relatively high reflectance. While the light passing through the light-emitting surface 12 to enter the optical fiber 30 extends over the wavelength range of about 1,540 nm to about 1,560 nm as shown in Fig. 2, the diffraction grating 35 reflects with a sufficient reflectance only the light extending over a wavelength width of about 0.3 nm whose center is about 1,553.3 nm as shown in Fig. 3. Accordingly, light with a wavelength width narrower than that obtained when the semiconductor laser 10 is used alone causes laser oscillation. Since the reflectance of the diffraction grating 35 with respect to the reflection wavelength is sufficiently higher than the reflectance of the light-reflecting surface 11, the output of the laser light due to laser oscillation between the diffraction grating 35 and the light-reflecting surface 11 becomes sufficiently higher than that generated by the semiconductor laser 10. As a result, the laser light output from the inspection light source 110 has a wavelength width narrower than that of the laser light output from the semiconductor laser 10.

Fig. 4 is a chart showing an oscillation spectrum of the inspection light source 110. As indicated by this chart, the inspection light source 110 performs single longitudinal mode laser oscillation. Of the light reflected by the diffraction grating 35, only light components exhibiting a relatively high reflectance satisfy the oscillation condition. Accordingly, the wavelength width (half-width) of the oscillation spectrum is about 0.1 nm, which is further narrower than the line width of the reflection spectrum of the diffraction grating 35.

Here, when the output wavelength width of the inspection light source 110 is 2 nm or smaller, characteristics of an optical fiber at a specific wavelength can be measured preferably. The output wavelength width of the inspection light source 110 can be adjusted when the line width of the reflection spectrum of the diffraction grating 35 is appropriately set.

The inspection light source 110 of this embodiment utilizes, as it is, a semiconductor laser which has conventionally been used as inspection light source, while adding the lens 20 and the optical fiber 30 thereto. Accordingly, while laser oscillation occurs between the diffraction grating 35 and the light-reflecting surface 11, laser oscillation also occurs in the semiconductor laser 10 between the light-reflecting surface 11 and the light-emitting surface 12. Nevertheless, since laser light with a narrow wavelength width can be obtained when laser oscillation is generated between the diffraction grating 35 and the light-reflecting surface 11, laser oscillation in the semiconductor laser 10 is not always necessary in practice. Accordingly, the reflectance of the light-emitting surface 12 can be made lower than that in this embodiment without the reflectance of the light-reflecting surface 11 being changed. Since the power of the light emitted from the light-emitting surface 12 is enhanced in this manner, the reflectance of the diffraction grating 35 may be made lower than that in this embodiment.

Since the OTDR apparatus 100 of this embodiment comprises the above-mentioned inspection light source 110 and thereby uses laser light with a sufficiently narrow wavelength width as inspection light, characteristics of the optical fiber 60 to be measured at a specific wavelength can be preferably measured.

Also, the inspection light source 110 has a simple configuration constituted by the semiconductor laser 10, the optical fiber 30, and the lens 20 for optically coupling them together. Thus, the number of parts in the OTDR apparatus 100 is remarkably smaller than that in the conventional OTDR apparatus using an optical fiber laser as its light source. Accordingly, the OTDR apparatus 100 of this embodiment is advantageous in that designing of optical systems and disposition of optical parts therein are easy, and that the apparatus can be made effortlessly with a smaller size. The small number of parts and the effortless manufacture lead to a low manufacturing cost. Accordingly, the OTDR apparatus of this embodiment is also suitable for mass production.

(Embodiment 2)

The OTDR apparatus of this embodiment differs from that of Embodiment 1 in that it comprises an inspection light source which, in addition to the constituents of the inspection light source 110 in Embodiment 1, further comprises a stress applying device 70 for applying a stress to the optical fiber 30.

Fig. 5 is a view showing a configuration of the stress applying device 70. The stress applying device 70 comprises arms 71 and 72 for holding the optical fiber 30 respectively at two points between which the diffraction grating 35 is held, and a piezoelectric device 73 to which the arms 71 and 72 are attached. To the piezoelectric device 73, a non-depicted variable voltage source is connected. The piezoelectric device 73 expands or contracts as a driving voltage is applied thereto from the variable voltage source. The direction of expansion or contraction is substantially in parallel to the optical-axis direction of the optical fiber 30.

When the piezoelectric device 73 expands or contracts, a stress (tension or pressure) is applied, by way of the arms 71 and 72, to the optical fiber 30 in the optical-axis direction. Consequently, the period of the diffraction grating 35 or the effective refractive index of the core changes. Since the reflection wavelength of the diffraction grating 35 depends on the period of the diffraction grating 35 and the effective refractive index of the core as indicated by the above-mentioned expression (1), the reflection wavelength of the diffraction grating 35 also changes in response to their changes. When the reflection wavelength changes, the output wavelength of the inspection light source also changes. Accordingly, when the magnitude or polarity of the driving voltage for the piezoelectric device 73 is adjusted so as to control the expansion and contraction of the piezoelectric device 73, the output wavelength of the inspection light source can be arbitrarily switched over. In this embodiment, an output wavelength change of 10 nm/kg can be realized.

Thus, since the OTDR apparatus of this embodiment comprises an inspection light source with a variable wavelength, it can select a wavelength from a predetermined variable wavelength range so as to measure characteristics of the optical fiber to be measured at this wavelength. While this inspection light source attaches the stress applying device 70 to the optical fiber 30 of the inspection light source 110 in Embodiment 1, no new optical parts are added thereto. Accordingly, as in the case of Embodiment 1, the OTDR apparatus of this embodiment is also advantageous in that designing of optical systems and disposition of optical parts therein are easy, and that the apparatus can be made effortlessly. Also, even though the stress applying device 70 is added thereto, the number of parts is still small, and the stress applying device 70 is a small device utilizing a piezoelectric device. Therefore, the OTDR apparatus as a whole can attain a sufficiently small size.

(Embodiment 3)

In the OTDR apparatus of this embodiment, the configuration of the inspection light source also differs from the inspection light source 110 of Embodiment 1. Namely, the inspection light source in the OTDR apparatus of this embodiment further comprises, in addition to the constituents of the inspection light source 110 in Embodiment 1, a temperature adjusting bath storaging the part of the optical fiber 30 including the diffraction grating 35. This temperature adjusting bath arbitrarily changes the temperature therein within a predetermined temperature range.

Also, in this embodiment, as shown in Fig. 6, the optical fiber 30 is buried in a V-shaped groove 91 of a stationary plate 90. To the part of the optical fiber 30 including the diffraction grating 35, a metal plate (aluminum plate) 80 is attached. This aluminum plate 80 is bonded by means of an adhesive to the optical fiber 30 at two positions between which the diffraction grating 35 is held.

When the temperature within the temperature adjusting bath is changed, a stress is applied to the optical fiber 30 in response to the difference between the coefficient of thermal expansion of the aluminum plate 80 and that of the optical fiber 30. Consequently, the part of the optical fiber 30 including the diffraction grating 35 expands or contracts along the optical-axis direction, whereby the period of the diffraction grating 35 changes to shift the reflection wavelength. Accordingly, when the temperature within the temperature adjusting bath is regulated, the output wavelength of the inspection light source can be arbitrarily switched over. In this embodiment, an output wavelength change of 0.05 nm/°C can be realized.

Here, since the optical fiber 30 itself expands or contracts when the temperature within the temperature adjusting bath changes, the reflection wavelength of the diffraction grating 35 can change even when the aluminum plate 80 is not provided. When the aluminum plate 80 is provided, however, the change in reflection wavelength with respect to change in temperature increases, whereby the output wavelength of the inspection light source can be advantageously switched over within a broader wavelength range. Also, better controllability is attained when the aluminum plate 80 is provided.

Since the OTDR apparatus in this embodiment also comprises a wavelength-variable inspection light source as in the case of the OTDR apparatus in Embodiment 2, it can select a wavelength from a predetermined variable wavelength range so as to measure characteristics of the optical fiber to be measured at this wavelength. Also, this inspection light source adds no new optical parts to the configuration of the inspection light in Embodiment 1 and, accordingly, is advantageous in that designing of optical systems and disposition of optical parts therein are easy, and that the apparatus can be made effortlessly.

(Embodiment 4)

First, a pulse laser light source used in the OTDR apparatus of this embodiment will be explained.

With reference to Figs. 7 to 11, a first example of the pulse laser light source will be explained. Initially, with reference to Fig. 7, provided in the apparatus is a semiconductor light-emitting device (Fabry-Perot type laser) 200 comprising a laser medium 202 made of a semiconductor having a hetero-structure of InGaAsP/InP, for example, and light-reflecting surfaces 204 and 206 which are opposed to each other and respectively disposed at both ends of the laser medium 202. One light-reflecting surface 204 has a high reflectance of about 80%, for example, while the other light-reflecting surface 206 has a low reflectance of about 5%, for example, such that the laser light stimulatively emitted at the laser medium 202 passes through and exits from the light-reflecting surface 206.

A condenser lens 208 is disposed so as to face the light-reflecting surface 206. Disposed to face the condenser lens 208 from behind is an end face of a core in an optical fiber 210 in which an optical waveguide type diffraction grating 212, which will be explained later, is formed. Here, both the position from which the laser light exits and the end face of the core in the optical fiber 210 are disposed so as to coincide with the optical axis of the condenser lens 208.

As shown in a longitudinal cross section depicted as being enlarged in Fig. 7, the optical waveguide type diffraction grating 212 has such a configuration that, as ultraviolet rays or the like have irradiated a part of a core 214 disposed in a clad 216 of the optical fiber 212 along the optical wave-guiding direction thereof, a plurality of refractive-index changing portions (depicted as banded portions) having refractive index n_2 which is different from original refractive index n_1 of the core 212 ($n_2 < n_1$ in this embodiment) are formed. Namely, it has a so-called refractive-index change distribution in which portions with refractive indices n_1 and n_2 periodically alternate with a predetermined pitch Δ along the optical wave-guiding direction, and exhibits a wavelength selectivity for selectively reflecting, of the light transmitted through this refractive-index change distribution, wavelength light with $\lambda = 2n_1\Delta$. Namely, when incident light is introduced into the core 212 from one end (side facing the condenser lens 208), the light with the wavelength λ returns toward the condenser lens 208 as reflected light due to the wavelength selectivity of the optical waveguide type diffraction grating 212, while the light excluding the wavelength λ is output to the other end as outgoing light. Here, the light transmittance of the optical waveguide type diffraction grating 212 is set to about 47%.

Disposed at the other end of the optical fiber 210 is an optical connector 218 for connecting the former to other optical fibers or the like.

Also provided are a driving section 220 for supplying a driving current (electric power) I for excitation to the laser medium 202, and a timing control circuit 222 for controlling the output timing of this driving current I. The driving section 220 comprises a stabilizing-power generating circuit 224 for outputting a stabilizing current (electric power) I_s for stabilizing laser oscillation which will be explained later or the like, and a pulse-power generating circuit 226 for outputting a pulse current (electric power) I_p, while the respective output timings of the currents I_s and I_p in these circuits 224 and 226 are controlled by the timing control circuit 222.

Further provided in the driving section 220 is a current adding circuit 228 which adds the currents I_s and I_p together so as to supply the driving current I (= $I_s + I_p$) to the laser medium 202.

In the following, the operation of the pulse laser apparatus thus configured will be explained with reference to Figs. 7 to 11.

The stabilizing-power generating circuit 224 in the driving section 220 continuously outputs a certain constant level of the stabilizing current I_s under the control of the timing control circuit 222 as shown in Fig. 8, whereas the pulse-power generating circuit 226 outputs the pulse current I_p having a pulse form such as that shown in Fig. 9 according to a control signal with a predetermined timing from the timing control circuit 222.

During a period which is not designated by the control signal from the timing control circuit 222, the pulse current I_p is 0 A; whereas, at the time indicated by the above-mentioned control signal, it is set to a current level I_m which is sufficient for exciting the laser medium 202. The stabilizing current I_s is set to a constant level of about 1/10 of the current level I_m, i.e., $I_m/10$. Also, the stabilizing current I_s is set to a level which is at a threshold current level necessary for the semiconductor light-emitting device 200 to generate laser oscillation or higher. As these currents I_s and I_p are added together at the current adding circuit 228, the driving current I (= $I_s + I_p$) such as that shown in Fig. 10 is supplied to the laser medium 202.

During the period in which the driving current I corresponds to the stabilizing current I_s (= $I_m/10$), the light excited by this current I_s in the laser medium 202 is introduced into the core 214 of the optical fiber 210 by way of the light-reflecting surface 206 and the condenser lens 208, and a part of the light with the reflection wavelength (Bragg wavelength) λ set in the optical waveguide type diffraction grating 212 is further reflected so as to be made incident on the laser medium 202 again by way of the condenser lens 208 and the light-reflecting surface 206, thereby contributing to the stimulated emission resulting from an interference phenomenon caused by the light-reflecting surfaces 204 and 206. Further, thus stimulatively emitted light is introduced into the core 214 of the optical fiber 210 by way of the light-reflecting surface 206 and the condenser lens 208, and a part of the light with the reflection wavelength (Bragg wavelength) λ set in the optical waveguide type diffraction grating 212 is further reflected so as to be made incident on the laser medium

202 again by way of the condenser lens 208 and the light-reflecting surface 206, thereby contributing to the above-mentioned stimulated emission. Accordingly, as the foregoing phenomenon of stimulated emission is continuously generated, the Fabry-Perot type laser emits laser light having a wavelength equal to the reflection wavelength λ set in the optical waveguide type diffraction grating 212. Here, since the driving current I during this period corresponds to the stabilizing current I_s (= $I_m/10$), the optical intensity of the laser light emitted during this period becomes lower than the desired intensity of pulse laser light. Specifically, since the relationship of $I_s = I_m/10$ is set, the former becomes lower than the latter by 10 dB.

Next, at the time in which the pulse current I_p is generated in the driving current I, as the driving current I rapidly increases, pulse laser light having a pulse form with a high optical intensity is emitted from the semiconductor light-emitting device 200 and, by way of the condenser lens 208 and the optical fiber 210 as well as the optical connector 218, is output as the outgoing light.

Fig. 11 schematically shows a result of measurement in which change in the spectrum distribution of the outgoing light output from the optical connector 218 is actually measured with time, with its Z axis indicating the optical intensity. From this chart, it has been confirmed that laser light at the wavelength λ with a low optical intensity is generated during the period in which the driving current laser becomes the stabilizing current I_s (= $I_m/10$), whereas pulse-shaped laser light at the wavelength λ with a high optical intensity is generated at the time when the pulse current I_p is supplied. In practice, laser light with a wavelength range having a half-width of about 0.3 nm whose center is the wavelength λ could be realized.

Further, it is necessary for the interval between adjacent supplies of the pulse current I_p (i.e., period during which only the stabilizing current I_s is supplied) to be set to a period during which the light emitted from the laser medium 202 is reflected by the optical waveguide type diffraction grating 212 and then returns to contribute to the stimulated emission (period for one to-and-fro travel) or longer. According to the result of actual measurement, when the pulse current I_p was supplied at the time after the stabilizing current I_s was continuously supplied over the period for about 200 to-and-fro travels, very stable pulse laser light with a narrow wavelength range could be output.

Thus, in the pulse laser light source of the first example, before the pulse laser light with a narrow wavelength range originally required is generated, the stabilizing current I_s is supplied to the semiconductor light-emitting device 200 so as to effect laser oscillation beforehand. Accordingly, at the time when the pulse current I_p is supplied, pulse laser light with a desired narrow wavelength range is obtained. Therefore, a pulse laser apparatus whose response is much better and whose stability concerning the narrow wavelength range is much more preferable as compared with those in the prior art can be provided. Namely, in the prior art, immediately after the pulse current is supplied to the pulse laser apparatus, light having a wide wavelength range is generated, thereby making it difficult to attain pulse laser light with a desired narrow wavelength range. The pulse laser light source of this example, by contrast, exhibits an excellent effect that pulse laser light with a stable narrow wavelength range can be obtained immediately after pulse current is supplied thereto.

During the period in which only the stabilizing current I_s is supplied to the laser medium 202, laser light, which may become a noise light component, is also output. Nevertheless, the optical intensity of this noise light component can be made smaller than that of the desired pulse laser light when the stabilizing current I_s is set to a level lower than that of the pulse current I_p as mentioned above. Accordingly, it does not result in a substantial problem when the pulse laser source is applied to fields of various optical instruments, optical communications, and the like.

Here, in the driving section 220 of the pulse laser light source in the first example, the stabilizing-power generating circuit 224 and the pulse-power generating circuit 226 are provided independently from each other so as to respectively output the stabilizing current I_s and the pulse current I_p, which are then added together in terms of current so as to generate the driving signal I. Without being restricted to such a configuration, however, the present invention may be configured so as to have a driving section which directly outputs the driving current I having a waveform shown in Fig. 10, for example.

In the following, the second example of the pulse laser light source used in the OTDR apparatus of this embodiment will be explained with reference to Figs. 12 to 15. Here, since the configuration of this apparatus is basically the same as the pulse laser source shown in Fig. 7, only their differences will be explained in detail without their overlapping explanations being repeated.

The stabilizing-power generating circuit 224 in Fig. 7 outputs the stabilizing current I_s having a rectangular shape as shown in Fig. 12 according to a control signal from the timing control circuit 222. Further, the pulse-power generating circuit 226 outputs the pulse current I_p having a pulse form as shown in Fig. 13 according to a control signal output from the timing control circuit 222. Here, timing control is perfomed such that the time width (generation period) of each rectangular block of the stabilizing current I_s is longer than that of the pulse current I_p, and that the stabilizing current I_s is synchronously output at a time which is prior, by a predetermined duration, to the time at which the pulse current I_p is output.

Accordingly, the driving current I (= $I_s + I_p$) supplied to the laser medium 202 in Fig. 7 changes stepwise as shown in Fig. 14. Here, during a period which is not designated by the control signal from the timing control circuit 222, the pulse current I_p is 0 A; whereas, at the time indicated by the above-mentioned control signal, it is set

to a current level I_m which is sufficient for exciting the laser medium 202. The stabilizing current I_s is set to a constant level of about 1/10 of the current level I_m, i.e., $I_m/10$. Also, the stabilizing current I_s is set to a level which is at a threshold current level necessary for the semiconductor light-emitting device 200 to generate laser oscillation or higher.

When the driving current I having a waveform shown in Fig. 14 is supplied to the semiconductor light-emitting device 200 in Fig. 7, laser light with the wavelength λ set at the optical waveguide type diffraction grating 212 is output, though with a low optical intensity, during the time in which the stabilizing current I_s is supplied alone; whereas pulse laser light having a high optical intensity and a narrow wavelength range with a center wavelength of λ is output when the driving current I, in which the pulse current I_p and the stabilizing current I_s are added together, is supplied.

Fig. 15 schematically shows a result of measurement in which change in the spectrum distribution of the outgoing light output from the optical connector 218 is actually measured with time, with its Z axis indicating the optical intensity. From this chart, it has been confirmed that, though light with a broad wavelength range is generated during a short period of time immediately after the driving current I rises from 0 A to $I_m/10$ (i.e., immediately after the stabilizing current I_s rises from 0 A to $I_s/10$); laser light at the wavelength λ with a low optical intensity is generated after this period has passed, and desired pulse-shaped laser light at the wavelength λ with a high optical intensity is generated at the time when the pulse current I_p is supplied. In practice, laser light with a wavelength range having a half-width of about 0.3 nm whose center is the wavelength λ could be realized.

Further, it is necessary for the interval between adjacent supplies of the pulse current I_p (i.e., period during which only the stabilizing current I_s is supplied) to be set to a period during which the light emitted from the laser medium 202 is reflected by the optical waveguide type diffraction grating 212 and then returns to contribute to the stimulated emission (period for one to-and-fro travel) or longer. It has been confirmed by examination that, when the pulse current I_p is supplied at the time after the stabilizing current I_s is continuously supplied over the period for about 200 to-and-fro travels, very stable pulse laser light with a narrow wavelength range can be output.

Thus, according to the pulse laser light source of the second example, though light having a broad wavelength range is slightly generated, a pulse laser light source whose response is much better and whose stability concerning the narrow wavelength range is much more preferable as compared with those in the prior art can be provided.

During the period in which only the stabilizing current I_s is supplied to the laser medium 202, laser light, which may become a noise light component, is also output. Nevertheless, the optical intensity of this noise light component can be made lower than that of the desired pulse laser light when the stabilizing current I_s is set to a level lower than that of the pulse current I_p as mentioned above. Accordingly, it does not result in a substantial problem when the pulse laser source is applied to fields of various optical instruments, optical communications, and the like.

Here, in the driving section 220 of the pulse laser light source in the second example, the stabilizing-power generating circuit 224 and the pulse-power generating circuit 226 are provided independently from each other so as to respectively output the stabilizing current I_s and the pulse current I_p, which are then added together in terms of current so as to generate the driving signal I. Without being restricted to such a configuration, however, the present invention may be configured so as to have a driving section which directly outputs the driving current I having a waveform shown in Fig. 14, for example.

In the following, a mode of realization of the OTDR apparatus in this embodiment will be explained with reference to Fig. 16. In Fig. 16, parts identical or equivalent to those in Fig. 7 will be referred to with marks identical to each other.

This OTDR apparatus comprises the semiconductor light-emitting device 200 and the driving section 220 both shown in Fig. 7, as well as a timing control circuit 230 provided in a microcomputer system or the like. This timing control circuit 230 outputs a control signal for making the driving section 220 supply the driving current I having a waveform such as that shown in Fig. 10 or 14 to the semiconductor light-emitting device 200 and also output a signal for controlling the operation timing of the OTDR apparatus as a whole.

The condenser lens 208 is disposed so as to face the light-emitting end of the semiconductor light-emitting device 200, and the core end of the optical fiber 210 having the optical waveguide type diffraction grating 212 is disposed so as to face the condenser lens 208 from behind, thereby realizing the pulse laser apparatus shown in Fig. 7.

To one side end of the optical fiber 210, a bidirectional light-splitting coupler 234 which optically connects to another optical fiber (referred to as "guiding fiber" hereinafter) 232 for guiding measurement light, which will be explained later, is connected. Connected to the terminator of the optical fiber 210 is an optical connector 236, to which an optical fiber transmission line 238 or the like to be inspected is connected.

One end of the guiding fiber 232 is terminated by a nonreflective material or the like which inhibits reflection of light, while the other end is connected to a measurement section having constituents 240 to 252 explained in the following.

Namely, connected to the other end of the guiding fiber 232 is a photodetector 240 having a photoelectric converter device for photoelectrically converting the measurement light guided by way of the light-splitting coupler 234. Further connected to the photodetector

240 in cascade are an amplifier circuit 242 for amplifying the photoelectrically-converted signal output from the former; an AC coupled circuit 244 having an offset eliminating circuit for eliminating AC components in the signal output from the amplifier circuit 242, a low-band eliminating filter, and the like; an A/D converter 246 for converting the signal passed through the AC coupled circuit 244 into digital data; an integrating and averaging circuit 248 for integrating the digital data with a predetermined operation period and computes the temporal mean value thereof; a logarithmic converter circuit 250 for logarithmically converting the temporal mean value output from the integrating and averaging circuit 248; and a display section 252 for displaying the logarithmic value data output from the logarithmic converter circuit 250 onto a CRT display or the like through various kinds of graphic processing.

Here, the A/D conversion timing in the A/D converter 246 and the operation period in the integrating and averaging circuit 248 are controlled by the timing control circuit 230. Further, their timings are in synchronization with the timing at which pulse laser light with a narrow wavelength range is output from the semiconductor light-emitting device 200 according to the driving current I.

In the following, the operation of the OTDR apparatus in this embodiment will be explained.

As the driving current I having such a waveform as that shown in Fig. 10 or 14 is supplied to the semiconductor light-emitting device 200, pulse laser light having a narrow wavelength range is emitted therefrom and introduced into the optical fiber transmission line 238 by way of the optical fiber 210, light-splitting coupler 234, and optical connector 236. Namely, thus obtained pulse laser light $h\nu_1$ having a narrow wavelength range becomes strobe light for inspecting whether there is abnormality or the like in the optical fiber transmission line 238 or not.

In the optical fiber transmission line 238, backscattering light advancing toward the opposite direction (toward the optical connector 236) is generated due to Rayleigh scattering and becomes measurement light $h\nu_2$, which is then guided to the guiding fiber 232 by way of the light-splitting coupler 234.

Thereafter, the photodetector 240 photoelectrically converts the measurement light $h\nu_2$ into a signal, which is then amplified by the amplifier circuit 242. After unnecessary AC components are eliminated therefrom by the AC coupled circuit 244, this signal is supplied to the A/C converter 246 so as to be converted into digital data. Further, as the integrating and averaging circuit 248 integrates the digital data and computes the mean value thereof, an optical power indicative of the degree of abnormality in the optical fiber transmission line 238, distance to the position where the abnormality is generated, or the like is extracted. This mean value is logarithmically converted by the logarithmic converter circuit 250, and thus converted value is displayed on the display section 252, thereby indicating the result of inspection of abnormality in the optical fiber transmission line 238.

As this OTDR apparatus uses pulse laser light having a very narrow wavelength range as strobe light $h\nu_1$ so as to measure an object to be measured, the distance to the point where the abnormality occurs in the object can be measured precisely, and measurement with a high S/N can be perfomed.

(Embodiment 5)

Fig. 17 is a view showing a configuration of an OTDR apparatus 100a in this embodiment. This OTDR apparatus 100a comprises an inspection light source 1a which oscillates in a pulsing manner to emit inspection laser light for OTDR test. This inspection light source 1a is formed as an optical fiber 30a is optically connected, by way of the lens 20, to the semiconductor light-emitting device (Fabry-Perot type semiconductor laser) 10 which has been conventionally used as inspection light source for OTDR apparatuses.

The Fabry-Perot type semiconductor laser 10 is a semiconductor light-emitting device constituted by a hetero-structure of InGaAsP/InP. To this semiconductor laser 10, a driving circuit 13 is connected. As the driving circuit 13 supplies an operating current flowing through the semiconductor laser 10, the latter is excited so as to output pulse laser light having a wavelength range of about 20 nm extending over the wavelength range of about 1,540 nm to about 1,560 nm. On both sides of the hetero-structure, the light-reflecting surface 11 and the light-emitting surface 12 are respectively disposed. These surfaces are opposed to each other substantially in parallel, thereby forming a Fabry-Perot type laser resonator. The light-reflecting surface 11 has a high reflectance of about 80%, while the light-emitting surface 12 has a low reflectance of about 5%. As in the case of most Fabry-Perot type devices, the semiconductor laser 10 is a multi-longitudinal-mode laser and yields large outputs in response to wavelengths in the respective modes.

The lens 20 converges the light emitted from the semiconductor laser 10 so as to make it incident on the optical fiber 30a, thereby coupling the semiconductor laser 10 to the optical fiber 30a in terms of optical power. As the lens 20, an ordinary optical coupling lens such as that used in optical communications can be employed. Here, a tip of the optical fiber 30a may be processed by melting or shaving to have a lens function, thereby eliminating the lens 20 which intervenes between the semiconductor laser 10 and the optical fiber 30a.

The optical fiber 30a comprises an ordinary single-mode optical fiber part and a diffraction grating 35 formed at a predetermined part of its core. It is disposed such that the light emitted from the semiconductor laser 10 is incident thereon by way of the lens 20. Though both core and clad of the optical fiber 30a are made of quartz (SiO_2) glass; the clad is made of substantially pure quartz glass while GeO_2, which is a material for

increasing refractive index, is added to the quartz glass constituting the core. As a result, the core of the optical fiber 30a has a refractive index which is higher than that of the clad by about 0.35%.

The diffraction grating 35 is disposed at a position where the optical path length (with respect to the output light of the semiconductor laser 10) from the light-reflecting surface 11 of the semiconductor laser 10 to the terminator (part farthest from the semiconductor laser 10) of the diffraction grating 35 is about 70 mm. This diffraction grating 35 is an area in the core where the effective refractive index thereof periodically changes between the minimum refractive index and the maximum refractive index according to positions along the optical axis. In other words, the diffraction grating 35 is an area having an effective refractive index distribution which repeatedly changes between the minimum refractive index and the maximum refractive index along the optical axis. Here, the period of this change in refractive index is referred to as period, grating pitch, or the like of the diffraction grating 35.

As is well known, a phenomenon that, when quartz glass doped with germanium is irradiated with ultraviolet rays, the refractive index of thus irradiated portion increases by an amount corresponding to the intensity of the ultraviolet rays can be utilized to form the diffraction grating 35. Namely, when an interference fringe of ultraviolet rays is projected onto the core doped with germanium from the clad surface of the optical fiber, an effective refractive index distribution corresponding to the optical intensity distribution of the interference fringe is formed at the area of the core irradiated with the interference fringe. The area having thus formed effective refractive index distribution is the diffraction grating 35. In this case, the minimum refractive index of the diffraction grating 35 substantially equals to the original effective refractive index (effective refractive index before the irradiation with ultraviolet rays) of the core.

The diffraction grating 35 reflects light over a wavelength range whose center is a predetermined reflection wavelength (Bragg wavelength) λ_R. This reflection wavelength λ_R is expressed as:

$$\lambda_R = 2 \cdot n \cdot \Lambda \qquad (1)$$

wherein n is the effective refractive index of the diffraction grating 35 and Λ is the period of the diffraction grating 35.

The diffraction grating 35 in this embodiment is a chirped grating in which the reflection wavelength λ_R monotonously changes according to positions along the optical axis. Since the reflection wavelength λ_R changes depending on both minimum refractive index and period of the diffraction grating as indicated by the above expression (1), the above-mentioned chirped grating encompasses (i) that having minimum refractive index monotonously changing according to positions along the optical axis and (ii) that having grating period monotonously changing according to positions along the optical axis. The diffraction grating 35 of this embodiment belongs to the latter type (ii) and has grating period which becomes greater at the position farther from the semiconductor laser 10 along the optical axis of the optical fiber 30a. The minimum refractive index of the diffraction grating 35 is substantially uniform along the optical axis, while the reflection wavelength of the diffraction grating 35 is longer at the position farther from the semiconductor laser 10 along the optical axis of the optical fiber 30a in response to the change in grating period.

Fig. 18 is a chart showing a reflection characteristic of the diffraction grating 35 in this embodiment. The vertical and horizontal axes in this chart indicate reflectance and wavelength, respectively. The peak shown in this chart is a reflection spectrum of the diffraction grating 35. This chart is obtained when a power spectrum of the light reflected by the diffraction grating 35 is determined and then the vertical axis of thus determined spectrum is converted into the ratio of the reflected light quantity to the incident light quantity, i.e., reflectance. As indicated by Fig. 18, the maximum reflectance of the diffraction grating 35 is about 40% with respect to the reflection wavelength of 1,550 nm, while the diffraction grating 35 has a reflection wavelength width of about 2 nm. Here, "reflection wavelength width of the diffraction grating 35" refers to the wavelength width between the intersections of the line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the diffraction grating 35 and the reflection spectrum of the diffraction grating 35 as shown in Fig. 18.

As shown in Fig. 17, the optical coupler 40 is connected to the inspection light source 1a. The optical coupler 40 is a kind of an optical directional coupler having four terminals, i.e., the first to third terminals 41 to 43 and the non-reflection terminal 44. The first terminal 41 is connected to the optical fiber 30a such that the inspection light from the inspection light source 1a is incident on the optical coupler 40. To the second terminal 42, the optical fiber 60 to be measured is connected. Accordingly, when incident on the optical coupler 40, the inspection light from the inspection light source 1a is split into two, and one of the split light components is made incident on the optical fiber 60 to be measured.

To the third terminal 43, the measurement section 50 is connected by way of an optical fiber 31. Accordingly, of the inspection light incident on the optical fiber 60 to be measured, backscattering light which has been made to advance in the opposite direction due to Rayleigh scattering at each point of the optical fiber 60 is made incident on the optical coupler 40 and split into two, and one of thus split light components is made incident on the measurement section 50.

As in the case of the conventional OTDR apparatus, an optical directional coupler such as optical circulator may be used in place of the optical coupler 40 in the OTDR apparatus of this embodiment.

The measurement section 50 measures the back-

scattering light of the optical fiber 60 to be measured. The measurement section 50, which is similar to that used in ordinary OTDR apparatuses, comprises a photodetector which detects the backscattering light of the optical fiber 60 and converts thus detected light into an electric signal; an amplifier for amplifying the electric signal output from the photodetector; a signal processing section which converts the signal output from the amplifier from analogue to digital and further subjects thus converted signal to an integrating and averaging processing, logarithmic conversion, or the like; a display device connected to the signal processing section; and the like. Here, the A/D conversion or integrating and averaging perfomed by the signal processing section is effected while the light emission timing of the semiconductor laser 10 is controlled by way of the driving circuit 13. Based on the output signal of the signal processing section, the display device displays the scattering light power of the optical fiber 60 with respect to the distance from a predetermined reference point to the measurement point in the optical fiber 60. As thus displayed waveform is observed, loss between two arbitrary points in the optical fiber 60 can be determined. Also, based on thus determined loss value, fusion-spliced points in the optical fiber 60 can be identified, for example.

In the following, the principle of light emission in the inspection light source 1a will be explained. When the driving circuit 13 supplies an operating current flowing through the Fabry-Perot type semiconductor laser 10, spontaneously emitted light is generated within the hetero-structure in the semiconductor laser 10. As this light is repeatedly reflected between the light-reflecting surface 11 and the light-emitting surface 12 while causing stimulated emission, the light is amplified so as to finally generate laser oscillation. In this manner, the light reflected by the light-emitting surface 12 contributes to laser oscillation of the semiconductor laser 10.

Nevertheless, since the reflectance of the light-emitting surface 12 is as low as 5%, most of the spontaneously emitted light and stimulatively emitted light can pass through the light-emitting surface 12. While being converged by the lens 20, the light transmitted through the light-emitting surface 12 is made incident on the optical fiber 30a and reaches the diffraction grating 35. As indicated by Fig. 18, the diffraction grating 35 reflects light over a reflection wavelength width of about 2 nm whose center is the reflection wavelength width λ_R. The light reflected by the diffraction grating 35 passes through the lens 20 and then is made incident, by way of the lens 20, on the semiconductor laser 10 from the light-emitting surface 12, and reaches the light-reflecting surface 11 while causing stimulated emission. The light reflected by the light-reflecting surface 11 advances, while causing stimulated emission, so as to be emitted from the light-emitting surface 12 and then incident on the optical fiber 30a again. This incident light reaches the diffraction grating 35, where it is reflected again. Thus, as reflection is repeated between the diffraction grating 35 and the light-emitting surface 11, light is amplified so as to finally generate laser oscillation. Thus generated laser light passes through the diffraction grating 35 and is emitted from the end face of the optical fiber 30a facing the optical coupler 40. Thus emitted laser light is inspection laser light output from the inspection light source 1a.

Fig. 19 is a chart showing a characteristic of inspection light output from the inspection light source 1a. The vertical and horizontal axes in this chart respectively indicate power of inspection light and wavelength. Also, the peak shown in this chart is a power spectrum of the inspection light. The light generating the laser oscillation between the diffraction grating 35 and the light-reflecting surface 11 is substantially restricted to, of the light emitted from the semiconductor laser 10, the light component included in the reflection wavelength range of the diffraction grating 35. In this embodiment, since the reflection wavelength width of the diffraction grating 35 is about 2 nm, the wavelength width of inspection light is also about 2 nm. Here, "wavelength width of inspection light" refers to the wavelength width between the intersections of the line drawn in parallel to the wavelength axis at a point where the power is lower than the maximum power of the inspection light by 20 dB and the power spectrum of the inspection light as shown in Fig. 19.

When the wavelength width of the inspection light used for an OTDR test is too small, time-coherency of the inspection light becomes so high that specific noise such as fading noise increases, thereby making it difficult to perfom the OTDR test with a high accuracy. According to experiments effected by the inventors, the noise level in OTDR tests becomes 0.15 dB or lower when the wavelength width of the inspection light is about 1 nm or greater. Since the loss at a point to which the optical connector is connected in the optical fiber is about 0.20 dB, when the noise level is 0.15 dB or lower, the connecting point of the optical conector and a noise can be distinguished from each other so as to identify the connecting point of the optical connector. Accordingly, this level is considered to be practical for OTDR apparatuses.

As explained in the foregoing, in the OTDR apparatus in this embodiment, since the reflection wavelength width of the diffraction grating 35 is broader than 1 nm, the wavelength width of the inspection light is also broader than 1 nm. As the time-coherency of the inspection light is sufficiently lowered thereby, OTDR tests with a high accuracy can be perfomed while fading noise is sufficiently suppressed. Actually, when the inventors perfomed an OTDR test by using the OTDR apparatus 100a of this embodiment, noise level was about 0.05 dB, and preferable results were obtained.

Also, in the OTDR apparatus 100a of this embodiment, since the reflection wavelength width of the diffraction grating 35 is narrower than 20 nm, which is the output wavelength width of the semiconductor laser 10, the wavelength width of inspection light is also narrower than the output wavelength width of the semiconductor

laser 10. Accordingly, in the OTDR apparatus 100a of this embodiment, characteristics of the optical fiber 60 to be measured at a specific characteristic can be measured preferably.

Further, since the diffraction grating 35 in the OTDR apparatus 100a of this embodiment is a chirped grating having a reflection wavelength width corresponding to the width of change in grating period. Accordingly, the reflection wavelength width of the diffraction grating 35 can be easily adjusted at the time when it is manufactured. The wavelength width of the inspection light output from the inspection light source 1a is determined according to the reflection wavelength width of the diffraction grating 35. Accordingly, the OTDR apparatus 100a of this embodiment can be easily made to output inspection light having a desired wavelength width.

Also, in the OTDR apparatus 100a of this embodiment, the diffraction grating 35 is disposed such that a part thereof on the short reflection wavelength side, i.e., the part with a smaller grating period, is directed toward the semiconductor laser 10. Accordingly, light from the semiconductor laser 10 advances from the part of the diffraction grating 35 on the short reflection wavelength side toward the long reflection wavelength side. This disposition is effected in view of the following phenomenon. As disclosed in a paper by K.O. Hill et al., "Application of Phase Masks to the Photolithographic Fabrication of Bragg Gratings in Conventional Fiber/Planar Waveguides with Enhanced Photosensitivity" (OFC PD, 15-1, 1993), the diffraction grating has a characteristic of outwardly emitting, at each part thereof, light having a wavelength shorter than the reflection wavelength at that part. Accordingly, when the diffraction grating 35, which is a chirped grating, is disposed such that the part thereof on the long reflection wavelength side is directed toward the semiconductor 10, the light which should be reflected at the part on the short reflection wavelength side is partially emitted outward at the time when it passes through the long reflection wavelength side, whereby, in the light reflected by the diffraction grating 35, the component on the short wavelength side becomes less than that on the longitudinal wavelength side. As a result, in the power spectrum of inspection light, the power on the short wavelength side becomes lower than that on the long wavelength side, whereby the inspection light does not have a uniform power over the wavelength range thereof.

In the OTDR apparatus 100a of this embodiment, since the diffraction grating 35 is disposed such that the part on the short reflection wavelength side is directed toward the semiconductor laser 10, such a phenomenon that the light which should be reflected at each part of the diffraction grating is emitted outward before being reflected can be prevented. As a result, the inspection light has a substantially uniform power over the whole wavelength range. Accordingly, the OTDR apparatus 100a of this embodiment can quite preferably perfom OTDR tests of the optical fiber 60 to be measured.

When the wavelength of the light reflected by the diffraction grating 35 has a significant width, it is preferable that the long-wavelength reflection side be disposed farther from the semiconductor laser 10 than is the short-wavelength reflection side, and that the wavelength distribution of reflectance in the diffraction grating 35 be set as explained in the following.

When the pulse width of inspection light is relatively long, the diffraction grating 35 is preferably disposed such that reflectance of the diffraction grating monotonously increases along the direction moving away from the semiconductor light-emitting device 10.

The wavelength light reflected at a position of the diffraction grating 35 farther from the semiconductor laser 10 has a longer resonator length, thereby having a more attenuated optical power. Accordingly, when the diffraction grating is disposed such that the reflectance thereof monotonously increases along the direction moving away from the semiconductor light-emitting device, the power of reflected light can be made substantially uniform regardless of the point of reflection. Therefore, inspection light having a substantially uniform power over the whole area of reflection wavelength can be used, whereby OTDR tests can be perfomed preferably.

When the pulse width of inspection light is short, by contrast, the diffraction grating 35 is preferably disposed such that reflectance of the diffraction grating monotonously decreases along the direction moving away from the semiconductor light-emitting device 10.

When the pulse width is shortened, there is a case where an effect that injection energy can be made smaller on the long wavelength side surpasses the influence of the resonator length. In such a case, when reflectance is made to decrease as the resonator length is longer, inspection light with a substantially uniform power over the whole reflection wavelength range can be output.

(Embodiment 6)

Fig. 20 is a view showing a configuration of an OTDR apparatus 100b in this embodiment. The OTDR apparatus 100b of this embodiment differs from that of Embodiment 1 in the configuration of an optical fiber 30b optically connected to the semiconductor laser 10 in an inspection light source 1b. Namely, in this embodiment, two diffraction gratings 36 and 37 are provided in a core of the optical fiber 30b.

The diffraction grating 37 is disposed at a position where the optical path length (with respect to the output light of the semiconductor laser 10) from the light-reflecting surface 11 of the semiconductor laser 10 to the terminator (part farthest from the semiconductor laser 10) of the diffraction grating 37 is about 70 mm. The diffraction grating 36 is disposed at a position closer to the semiconductor laser 10 than is the diffraction grating 37.

Each of the diffraction gratings 36 and 37 is a diffraction grating with a constant pitch, in which a prede-

termined grating period is maintained along the optical axis. The diffraction grating 36 has a period smaller than that of the diffraction grating 37, while their minimum refractive indices nearly equal to each other. Consequently, the diffraction grating 36 has a reflection wavelength smaller than that of the diffraction grating 37. Specifically, the reflection wavelength of the diffraction grating 36 is about 1,550 nm, whereas that of the diffraction grating 37 is about 1,554 nm. The reflection wavelength width of each diffraction grating is about 1 nm. Here, "reflection wavelength width of the diffraction grating" is defined as explained for Embodiment 5.

The area composed of the diffraction gratings 36 and 37 can be regarded as a single reflecting area 38 which reflects light over a predetermined wavelength range. Fig. 21 is a chart showing a reflection characteristic of this reflecting area, where a reflection spectrum made of two peaks corresponding to the respective diffraction gratings is exhibited. The reflection wavelength width of this reflecting area 38 is about 5 nm Here, "reflection wavelength width of the reflecting area 38" refers to, among the intersections between the line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the reflecting area 38 and the reflection spectrum of the reflecting area 38, the wavelength width between the point at which the wavelength is maximized and the point at which the wavelength is minimized as shown in Fig. 21.

In this embodiment, of the light emitted from the semiconductor laser 10, the light component repeatedly reflected between the light-reflecting surface 11 of the semiconductor laser 10 and the reflecting area 38 is subjected to laser oscillation and then output from the inspection light source 1b as inspection light. Fig. 22 is a chart showing a characteristic of this inspection light. In this embodiment, since the reflecting area 38 composed of the diffraction gratings 36 and 37 has a reflection wavelength width of about 5 nm, the inspection light also has a reflection wavelength width of about 5 nm. Here, "reflection wavelength width of inspection light" refers to the wavelength width between the intersections of the line drawn in parallel to the wavelength axis at a point where the power is lower than the maximum power of the inspection light by 20 dB and the power spectrum of inspection light as shown in Fig. 22.

Thus, in the OTDR apparatus 100b of this embodiment, since the reflecting area 38 composed of two diffraction gratings 36 and 37 having reflection wavelengths different from each other is provided in the optical fiber 30b, even when each diffraction grating has a small reflection wavelength width, and each of light components reflected by the respective diffraction gratings and subjected to laser oscillation has a high time-coherency, these light components are output from the inspection light source 1b as being superposed on each other, thereby yielding a sufficiently low time-coherency in the inspection light. In particular, in this embodiment, since the reflecting area 38 has a reflection wavelength width of 1 nm or greater, the wavelength width of inspection light also becomes broader than 1 nm. Accordingly, the time-coherency of inspection light can be securely lowered. Therefore, OTDR tests with a high accuracy can be securely perfomed while fading noise is sufficiently suppressed. Actually, when the inventors perfomed an OTDR test by using the OTDR apparatus 100b of this embodiment, noise level was about 0.05 dB, and preferable results were obtained.

Also, in the OTDR apparatus 100b of this embodiment, since the reflection wavelength width of the reflecting area 38 provided in the optical fiber 30b is narrower than 20 nm, which is the output wavelength width of the semiconductor laser 10, the wavelength width of inspection light is also narrower than the output wavelength width of the semiconductor laser 10. Accordingly, in the OTDR apparatus 100b of this embodiment, characteristics of the optical fiber 60 to be measured at a specific characteristic can be measured preferably.

Further, in the OTDR apparatus 100b of this embodiment, since, of the diffraction gratings 36 and 37 constituting the reflecting area 38, the diffraction grating 36 having a shorter reflection wavelength is disposed closer to the semiconductor laser 10, so that the light from the semiconductor laser 10 successively enters the diffraction gratings from the diffraction grating 36 having a shorter reflection wavelength. As previously noted in explanation for Embodiment 5, a diffraction grating has a characteristic of outwardly emitting, at each part thereof, light having a wavelength shorter than the reflection wavelength at that part. Nevertheless, when the diffraction gratings 36 and 37 are disposed as in the case of this embodiment, such a phenomenon that the light which should be reflected at the diffraction gratings is emitted outward before being reflected can be suppressed. As a result, the inspection light has a substantially uniform power over the whole wavelength range. Accordingly, the OTDR apparatus 100b of this embodiment can quite preferably perfom OTDR tests of the optical fiber 60 to be measured.

(Embodiment 7)

Fig. 23 is a view showing a configuration of an OTDR apparatus 100c in this embodiment. The OTDR apparatus 100c of this embodiment differs from that of Embodiment 6 in the configuration of a reflecting area 39 provided in an optical fiber 30c optically connected to the semiconductor laser 10 in an inspection light source 1c. This reflecting area 39 is formed as the same area of the core doped with germanium in a quartz type single-mode optical fiber is sequentially irradiated with ultraviolet interference fringes having periods different from each other. The periods of the respective interference fringes are adjusted so as to form constant-pitch diffraction gratings having reflection wavelengths of 1,550 nm and 1,554 nm, respectively. Accordingly, in the reflecting area 39, a constant-pitch diffraction grating having a reflection wavelength of 1,550 nm and a constant-pitch diffraction grating having a reflection

wavelength of 1,554 nm are disposed at one portion of the optical fiber as being superposed on each other.

This reflecting area 39 exhibits a reflection spectrum such as that obtained when the reflection spectrum of the diffraction grating having a reflection wavelength of 1,550 nm and the reflection spectrum of the diffraction grating having a reflection wavelength of 1,554 nm are superposed on each other. Thus formed reflection spectrum is substantially the same as that (Fig. 21) of the reflecting area 38 in the OTDR apparatus of Embodiment 6, and the reflection wavelength width thereof is about 5 nm, Accordingly, the wavelength width of inspection light output from the inspection light source 1c also becomes about 5 nm.

In this embodiment, of the light emitted from the semiconductor laser 10, the light component repeatedly reflected between the light-reflecting surface 11 of the semiconductor laser 10 and the reflecting area 39 is subjected to laser oscillation and then output from the inspection light source 1c as inspection light. This inspection light has a characteristic substantially identical to that of the inspection light in Embodiment 6 shown in Fig. 22, and has a reflection wavelength width of about 5 nm corresponding to the reflection wavelength width of the reflecting area 39.

Thus, since the OTDR apparatus 100c of this embodiment has the reflecting area 39 composed of two diffraction gratings having reflection wavelengths different from each other provided in the same portion of the optical fiber 30c, even when each diffraction grating constituting the reflecting area has a small reflection wavelength width, and each of light components reflected by the respective diffraction gratings and subjected to laser oscillation has a high time-coherency, these light components are output from the inspection light source 1c as being superposed on each other, thereby yielding a sufficiently low time-coherency in the inspection light. In particular, in this embodiment, since the reflecting area 39 has a reflection wavelength width of 1 nm or greater, the wavelength width of inspection light becomes broader than 1 nm. Accordingly, the time-coherency of inspection light can be lowered securely and sufficiently. Therefore, OTDR tests with a high accuracy can be securely perfomed while fading noise is sufficiently suppressed. Actually, when the inventors perfomed an OTDR test by using the OTDR apparatus 100c of this embodiment, noise level was about 0.05 dB, and preferable results were obtained.

Also, in the OTDR apparatus 100c of this embodiment, since the reflection wavelength width of the reflecting area 39 provided in the optical fiber 30c is narrower than 20 nm, which is the output wavelength width of the semiconductor laser 10, the wavelength width of inspection light is also narrower than the output wavelength width of the semiconductor laser 10. Accordingly, in the OTDR apparatus 100c of this embodiment, characteristics of the optical fiber 60 to be measured at a specific characteristic can be measured preferably.

(Embodiment 8)

Fig. 24 is a view showing a configuration of an OTDR apparatus 100d in this embodiment. The OTDR apparatus 100d of this embodiment differs from that of the above-mentioned embodiment in the configuration of an inspection light source 1d. Namely, in the inspection light source 1d, the diffraction grating 36 is formed in an optical fiber 30d optically connected to the semiconductor laser 10, while a stress applying device 70 is further attached to a part including the diffraction grating 36.

The diffraction grating 36 is a constant-pitch diffraction grating maintaining a predetermined grating pitch along the optical axis. The reflection wavelength of the diffraction grating 36 is about 1,550 nm, with a reflection wavelength width of about 1 nm.

The stress applying device 70 comprises arms 71 and 72 which hold the optical fiber 30d respectively at two points between which the diffraction grating 36 is held, and a piezoelectric device 73 having both ends respectively attached to the arms 71 and 72. Connected to the piezoelectric device 73 is a non-depicted variable voltage source, from which a driving voltage is applied to the piezoelectric device 73 so as to make the latter expand or contract. Here, the directions of expansion and contraction are substantially in parallel to the optical-axis direction of the optical fiber 30d.

When the piezoelectric device 73 expands or contracts, a stress (tension or pressure) is applied to the optical fiber 30d along the optical-axis direction by way of the arms 71 and 72. As a result, the period or minimum refractive index of the diffraction grating 36 changes. As indicated by the above-mentioned expression (1), the reflection wavelength of the diffraction grating 36 depends on the period and minimum refractive index of the diffraction grating 36. Accordingly, the reflection wavelength of the diffraction grating changes in response to the change in the period and minimum refractive index thereof. According to experiments effected by the inventors, the reflection wavelength of the diffraction grating 36 can be increased by about 1 nm when a tension of 100 g is applied thereto.

In this embodiment, of the light emitted from the semiconductor laser 10, the light component repeatedly reflected between the light-reflecting surface 11 of the semiconductor laser 10 and the diffraction grating 36 is subjected to laser oscillation and then output from the inspection light source 1d as inspection light. Since the wavelength range of the inspection light is determined according to the reflection wavelength range of the diffraction grating 36, the wavelength range of the inspection light changes when the reflection wavelength of the diffraction grating 36 changes. Accordingly, when the driving voltage of the piezoelectric device 73 is adjusted so as to control the expansion and contraction of the piezoelectric device 73, the wavelength range of the inspection light can be arbitrarily regulated.

Actually, as shown in the reflection characteristic

chart of Fig. 25, when the stress applying apparatus 70 shifts the reflection wavelength of the diffraction grating 36 by about 4 nm, thereby shifting the reflection wavelength range by a wavelength width of about 5 nm; the maximum power of the inspection light also shifts by about 4 nm as shown in the inspection light characteristic chart of Fig. 26. Accordingly, when the driving voltage level is periodically changed with time so as to periodically change the reflection wavelength range of the diffraction grating 36 with time with a wavelength width of about 5 nm, the wavelength range of the inspection light also periodically changes with a wavelength width of about 5 nm. In this case, the inspection light source 1d is equivalent to a light source having a wavelength width of about 5 nm. Here, "changing the reflection wavelength range of the diffraction grating 36 with time with a wavelength width of about 5 nm" refers to a case where the reflection wavelength range is changed with time such that, in a reflection characteristic chart of the diffraction grating 36, when an intersection between a line drawn in parallel to the wavelength axis at a point which is 1/10 of the maximum reflectance of the diffraction grating 36 and the reflection spectrum of the diffraction grating 36 is determined per time, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized becomes about 5 nm. Also, "wavelength range of the inspection light periodically changes with time with a wavelength width of about 5 nm" refers to a case where the wavelength range changes with time such that, in a characteristic chart of the inspection light, when an intersection between a line drawn in parallel to the wavelength axis at a point where power is lower than the maximum power of the inspection light by 20 dB and the power spectrum of the inspection light is determined per time, the wavelength width between the point at which the wavelength is minimized and the point at which the wavelength is maximized becomes about 5 nm.

Thus, in the OTDR apparatus 100d of this embodiment, as the reflection wavelength range of the diffraction grating 36 is changed with time by the stress applying apparatus 70, the wavelength range of inspection light can be changed with time, whereby inspection light having a substantially broad wavelength width and a sufficiently low time-coherency can be obtained. Accordingly, in the OTDR apparatus 100d of this embodiment, OTDR tests with a high accuracy can be securely perfomed while fading noise is sufficiently suppressed. Actually, when the inventors perfomed an OTDR test by using the OTDR apparatus 100d of this embodiment, noise level was about 0.05 dB, and preferable results were obtained.

Also, in the OTDR apparatus 100d of this embodiment, since the substantial reflection wavelength width of the diffraction grating 36 is narrower than 20 nm, which is the output wavelength width of the semiconductor laser 10, the substantial wavelength width of inspection light is also narrower than the output wavelength width of the semiconductor laser 10. Accordingly, in the OTDR apparatus 100d of this embodiment, characteristics of the optical fiber 60 to be measured at a specific characteristic can be measured preferably.

Though the stress applying device 70 is used to apply a stress to the diffraction grating 36 so as to change the reflection wavelength range of the latter in this embodiment, the part of the optical fiber 30d including the diffraction grating 36 may be accommodated in a temperature adjusing bath instead, and the temperature within the bath may be changed. When the temperature around the diffraction grating 36 changes, the diffraction grating 36 expands or contracts along the optical-axis direction, thereby changing the reflection wavelength of the diffraction grating 36. Accordingly, when the temperature within the temperature adjusting bath is regulated, the wavelength range of inspection light can be adjusted. In this case, when a member (e.g., plate made of a metal such as aluminum) having a coefficient of thermal expansion different from that of the optical fiber 30d is attached to the part of the optical fiber 30d including the diffraction grating 36, the change in reflection wavelength of the diffraction grating due to the change in temperature preferably increases. According to experiments effected by the inventors, when the aluminum plate is attached thereto, the reflection wavelength of the diffraction grating 36 can be increased by 2 nm as the temperature within the temperature adjusting bath is raised by 10°C.

Figs. 27 and 28 are configurational views respectively showing modified examples of the OTDR apparatus in accordance with the above-mentioned Embodiment 1. Fig. 27 shows an OTDR apparatus in which an optical isolator 91 and a transmission type band pass filter 92 are inserted between the inspection light source 110 and the optical coupler 40. Fig. 28 shows an OTDR apparatus in which an optical circulator 30a is adopted, and a reflection type band pass filter 93 is inserted in an optical path between the inspection light source 110 and the optical fiber 60 to be measured.

In the embodiments where one of facing mirrors of the inspection light source 110 is constituted by the diffraction grating 35 formed in the optical waveguide 30, the wavelength width of the oscillated laser light is made narrower. Nevertheless, when the resonator length becomes large, due to its relationship to pulse width, the number of to-and-fros of light through the resonator decreases. Accordingly, though with a low power, oscillation wavelength cannot be prevented from expanding. When an OTDR test is perfomed, there are cases where, in order to prevent crosstalk to a signal transmission band from occurring, such an extension of oscillation wavelength is desired to be reduced in an amount beyond the capacity of the diffraction grating.

In such cases, when a band pass filter is further provided in an optical path between the inspection light source 110 and the optical fiber 60 to be measured, light outside of the wavelength range necessary for the OTDR apparatus can be cut off, whereby a preferable

output characteristic can be obtained. As a result, influence upon optical communications can be securely suppressed.

(Embodiment of Optical communication line Inspection System)

Fig. 29 is an overall configurational view showing an optical communication line inspection system of this embodiment. First, a basic configuration of an optical communication network to which the inspection system of this embodiment is applied will be explained. One or a plurality of optical communication lines 303 (represented by three optical communication lines in Fig. 29) connected to a transmission apparatus 302, which is installed in a station for a subscriber communication network or the like, are bundled as an optical fiber cable 304 and extend to subscribers' houses 305. Accordingly, the transmission apparatus 302 and each subscriber's house 305 is connected to each other by way of one optical communication line 303. Communication light output from the transmission apparatus 302 is propagated through the optical communication line 303 and received by a terminal installed at the subscriber's house 305. In the optical communication network of this embodiment, signal light having a wavelength of about 1,300 nm is used.

In the following, the configuration of the inspection system in this embodiment will be explained. This inspection system is constituted by an OTDR apparatus 300; an optical switch 340 connected, by way of an optical fiber 322, to inspection light from the OTDR apparatus 300; an optical coupler 350 disposed at the end portion of the optical communication line 303 on the transmission apparatus side 302; and an optical filter 360 disposed at the terminator portion (end portion on the subscriber side 305) of each optical communication line 303.

The OTDR apparatus 300 is constituted by a light-emitting section 310; an optical coupler 320 connected to the light-emitting section 310 by way of an optical fiber 323; and an inspection section 330 connected to the optical coupler 320 by way of the optical fiber 323.

The light-emitting section 310 oscillates in a pulsing manner to emit laser light which is inspection light. The half-width of wavelength spectrum of this inspection light, i.e., wavelength width, is about 20 nm. The center wavelength (wavelength at the center of the half-width) is about 1,550 nm, which is different from the wavelength of the signal light.

The optical coupler 320 makes the inspection light, which is incident thereon by way of the optical fiber 321, incident on the optical switch 340 by way of the optical fiber 322; while making the returned inspection light, which has been reflected or scattered by each part of the optical communication line 303 and optical filter 360, incident on the inspection section 330 by way of the optical fiber 323.

The inspection section 330 detects thus returned inspection light so as to inspect the state of the optical communication line 303. This inspection section 330, which is similar to that used in ordinary OTDR apparatuses, comprises a photodetector for detecting the inspection light and converting thus detected inspection light into an electric signal, an amplifier for amplifying the electric signal output from the photodetector, a signal processor for A/D-converting the signal output from the amplifier and subjecting thus converted signal to an averaging processing or the like; a CRT device connected to the signal processor; and the like.

The optical switch 340 optically connects the optical coupler 320 within the OTDR apparatus 300 and one of the optical couplers 350 in the optical communication line 303 to each other by way of an optical fiber 341 in a switching manner. As the inspection light from the OTDR apparatus 300 is made incident on the optical communication line 303 including the connected optical coupler 350, the optical communication line 303 to be inspected can be selected as the optical switch 340 is operated.

The optical coupler 350 makes the inspection light incident on the optical communication line 303 so as to be propagated toward the subscriber's house 305; while making the returned inspection light, which has been reflected or scattered by each part of the optical communication line 303 and optical filter 360, incident on the optical switch 340.

Here, as can be seen from the foregoing, the optical coupler 320, the optical switch 340, and the optical coupler 350, as a whole, function to make the inspection light incident on the optical communication line 303, while making the reflected light and backscattering light from the optical communication line 303 incident on the inspection section 330. Namely, the optical coupler 320, the optical switch 340, and the optical coupler 350 constitute an optical functional section exhibiting such functions.

The optical filter 360 has a function of reflecting light over a predetermined wavelength range so as to cut off the inspection light immediately in front of the subscriber's house 305, thereby preventing the inspection light from becoming noise in optical communications. The inspection section 330 recognizes the terminator of the optical communication line 303 by detecting the light reflected by the optical filter 360. Here, in order to fully exhibit the function of cutting off the inspection light, the optical filter 306 preferably has a reflection wavelength width greater than the wavelength width of the inspection light.

Fig. 30 is a chart schematically showing a reflection spectrum of the optical filter 360 and a wavelength spectrum of inspection light. As indicated by this chart, the optical filter 360 preferably has a reflection wavelength width (half-width of reflection spectrum) broader than the wavelength width of the inspection light.

The optical filter 360 of this embodiment is constituted by a plurality of optical waveguide type diffraction gratings disposed in the optical communication line 303.

An optical waveguide type diffraction grating is an area of a core of an optical waveguide where the effective refractive index of the core periodically changes between the minimum refractive index and the maximum refractive index along the optical axis. This optical waveguide type diffraction grating reflects light having a relatively narrow wavelength width whose center is a predetermined reflection wavelength (Bragg wavelength). It has been known in general that the optical waveguide type diffraction grating can be manufactured as an optical waveguide is irradiated with an interference fringe of ultraviolet rays, for example. Such a manufacturing method is also disclosed in Japanese Publication of the Translation of International Application No. 62-500052.

Though each of the plurality of optical waveguide type diffraction gratings constituting the optical filter 360 has a single period, the periods slightly differ from each other among the respective optical waveguide type diffraction gratings. Thus, when a plurality of optical waveguide type diffraction gratings respectively having periods slightly different from each other are serially disposed in the optical communication line 303 so as to constitute the optical filter 360, the optical filter 360 exhibits a reflection spectrum with a broad wavelength width in which reflection spectra of the respective diffraction gratings partially overlap with each other. As the number of the optical waveguide type diffraction gratings is greater, the reflection wavelength width becomes broader. An optical filter having such a configuration is disclosed in a paper of R. Kashyap et al., "Novel Method of Producing All Fibre Photoinduced Chirped Gratings" (Electronics Letters, 9th June 1994, Vol. 30, No. 12).

In order to secure a preferable function as optical filter, a higher reflectance is more preferable in the optical waveguide type diffraction grating. Accordingly, an optical waveguide is exposed to a hydrogen atmosphere and then irradiated with an ultraviolet interference fringe so as to form an optical waveguide type diffraction grating used in this embodiment. According to this method, an optical waveguide type diffraction grating having a high reflectance can be obtained, whereby the reflectance of the optical filter 360 can also be made high. Nevertheless, since OH groups generated upon ultraviolet irradiation may absorb signal light, thereby increasing the transmission loss; the number of the optical waveguide type diffraction gratings constituting the optical filter 360 is preferably as small as possible.

Since the optical communication line 303 includes an optical fiber which is an optical waveguide, the optical filter 360 may be directly formed in the optical communication line 303. Also, an optical fiber or thin-film waveguide in which the optical filter 360 has been formed beforehand may be connected to the optical communication line 303 so as to provide the optical filter 360.

In the following, a method of inspecting an optical communication line by use of the inspection system in accordance with this embodiment will be explained. The inspection light output from the light-emitting section 310 is propagated through the optical fiber 321 so as to be incident on the optical coupler 320, where it is then split into two. While one of thus split inspection light components reaches the resistive terminator of the optical coupler 320, the other is propagated through the optical fiber 322 so as to be incident on the optical switch 340. This part of the inspection light is made incident, by way of the optical fiber 341 and the optical coupler 350, on the optical communication line 303 to be measured, and then advances through the optical communication line 303 to reach the optical filter 360.

Due to Fresnel reflection at a fault position (e.g., disconnected position) or Rayleigh scattering at each point of the optical communication line 303, a part of the inspection light returns in the direction opposite to the advancing direction. Each of the reflected light and backscattering light thus returned is split into two by the optical coupler 350, and one of thus split light components is made incident on the optical switch 340. Thereafter, the reflected light and backscattering light from the optical communication line 303 is propagated through the optical fiber 322 so as to be split into two by the optical coupler 320, and one of thus split light components is propagated through the optical fiber 323 so as to be incident on the inspection section 330.

The inspection section 330 detects the reflected light and backscattering light from the optical communication line 303 and optical filter 360 and subjects them to a signal processing, whereby the power of the reflected light or backscattering light of the optical communication line 303 is displayed on the CRT device with respect to the distance from a predetermined reference point to the measurement point. As thus displayed waveform is observed, the fault position in the optical communication line 303 as well as loss between two arbitrary points in the optical fiber 303 can be determined. In this manner, the inspection of the optical communication line 303 is performed.

In the optical communication line inspection system of this embodiment, since the light-emitting section 310 outputs light having a wavelength range as narrow as about 20 nm or less, the reflection wavelength width of the optical filter 360 can also be narrowed in response thereto. Accordingly, the number of the optical waveguide type diffraction gratings constituting the optical filter 360 may be made small. In particular, when the wavelength width of inspection light is about 5 nm or less, the number of the optical waveguide type diffraction gratings can be made very small, whereby the optical filter 360 can be constituted by a single optical waveguide type diffraction grating.

When the number of the optical waveguide type diffraction gratings is made small, the number of the above-mentioned OH groups can be reduced as well, whereby loss in transmission of the signal light can be suppressed. Also, in the case where the number of the optical waveguide type diffraction gratings is small, mode-mismatching occurring at the time when the sig-

nal light passes through the diffraction gratings can be reduced. Accordingly, transmission loss can be suppressed in this respect as well. Thus, in accordance with the optical communication line inspection method of this embodiment, inspection of optical communication lines can be performed while influence upon optical communications is sufficiently suppressed.

As the light-emitting section 10, a variety of configurations can be adopted. Figs. 31 to 34 are schematic views showing configurational examples 310a to 310d of the light-emitting section 310. In the following, these examples will be explained with reference to their corresponding drawings.

First, the light-emitting section 310a of Fig. 31 is constituted by a Fabry-Perot type semiconductor laser 370, lenses 371 and 374, an isolator 372, and an optical filter 373. Here, the optical filter 373 in this example is a dielectric multilayer film filter.

The Fabry-Perot type semiconductor laser 370 has an oscillation wavelength width of about 30 nm. The lens 371 converts the laser light output from the semiconductor laser 370 into a parallel beam and makes this beam incident on the isolator 372. The isolator 372 has a forward direction toward the direction of arrow in the drawing, while cutting off the light advancing in the opposite direction. The laser light transmitted through the isolator 372 is made incident on the optical filter 373.

The optical filter 373 restricts the wavelength width of the laser light from the semiconductor laser 370 such that, of the light included in the oscillation wavelength range of the semiconductor laser 370, a light component having a wavelength width of about 20 nm or less whose center is a predetermined wavelength passes therethrough. Though a part of the laser light from the semiconductor laser 370 may be reflected by the optical filter 373, such reflected light is cut off by the isolator 372. Similarly, the reflected light and scattered light from the optical communication line are cut off. Accordingly, the light is prevented from being incident on the resonator of the semiconductor laser 370 and disturbing a stable oscillation state.

The laser light transmitted through the optical filter 373 is made incident on the lens 374. While converging the parallel beam of laser light, the lens 374 makes the laser light incident on the optical fiber 321. The laser light emitted from the lens 374 is inspection light output from the light-emitting section 310a. As mentioned above, when the laser light from the semiconductor laser 370 passes through the optical filter 373, inspection light having a wavelength range of about 20 nm or less is realized.

Next, the light-emitting section 310b of Fig. 32 is constituted by the Fabry-Perot type semiconductor laser 370, a lens 375, optical fibers 376 and 378, and an optical circulator 377. To the optical circulator 377, the optical fibers 376 and 378 as well as the optical fiber 321 are connected. In a part of a core of the optical fiber 378, an optical waveguide type diffraction grating 379 is disposed.

As in the case of the light-emitting section 310a of Fig. 31, the semiconductor laser 370 has an oscillation wavelength width of about 30 nm. The lens 375 converges the laser light output from the semiconductor laser 370 and makes thus converged light incident on the optical fiber 376, thereby connecting the semiconductor laser 370 to the optical fiber 376 in terms of optical power. The laser light incident on the optical fiber. 376 enters the optical circulator 377 and then is emitted to the optical fiber 378. This laser light advances through the optical fiber 378 and reaches the optical waveguide type diffraction grating 379. The optical waveguide type diffraction grating 379 reflects, of the light included in the oscillation wavelength range of the semiconductor laser 370, a light component having a wavelength width of about 20 nm or less. This reflection light is made incident on the optical circulator 377 and then emitted to the optical fiber 321. The light incident on the optical fiber 321 by way of the optical circulator 377 is inspection light of the light-emitting section 310b.

Thus, since the light-emitting section 310b uses the light reflected by the optical waveguide type diffraction grating 379 as inspection light, when the reflection wavelength of the diffraction grating is about 20 nm or less, the wavelength width of inspection light also becomes about 20 nm or less. Since it is easy to prepare the optical waveguide type diffraction grating having a narrow wavelength width, inspection light having a wavelength width of 5 nm or less can be easily realized in accordance with the light-emitting section 310b.

Here, an optical fiber whose tip has been processed by melting or shaving to have a lens function may be used as the optical fiber 376, thereby eliminating the lens 375 which intervenes between the semiconductor laser 370 and the optical fiber 376.

Next, the light-emitting section 310c of Fig. 33 is constituted by a distribution feedback (DFB) type semiconductor laser 380, the lenses 371 and 374, and the isolator 372. The laser light output from the distribution feedback type semiconductor laser 380 is converted into a parallel beam by the lens 371 and then made incident on the isolator 372. The isolator 372 has a forward direction toward the direction of arrow in the drawing, while cutting off the light advancing in the opposite direction. Accordingly, the reflected light or backscattering light from the optical communication line 303 is prevented from being incident on the resonator of the semiconductor laser 380 and disturbing a stable oscillation state. The light transmitted through the isolator 372 is incident on the lens 374 and then, while being converged, enters the optical fiber 321. The laser light emitted from the lens 374 is the output inspection light of the light-emitting section 310c.

The wavelength width of inspection light output from the light-emitting section 310c equals to the oscillation wavelength width of the distribution feedback type semiconductor laser 380. The distribution feedback type semiconductor laser 380 has a strong longitudinal-mode selectivity and a very narrow oscillation wave-

length width. Therefore, in accordance with the light-emitting section 310c, the wavelength width of the output inspection light can be easily set to about 20 nm or less, and inspection light having a wavelength width of about 5 nm or less can be easily realized.

Finally, the light-emitting section 310d of Fig. 34 is constituted by a Fabry-Perot type semiconductor laser 388, the lens 375, and an optical fiber 384. In a core of the optical fiber 384, an optical waveguide type diffraction grating 385 is formed. Also, to the optical fiber 384, the optical fiber 321 is connected.

This light-emitting section 310d is similar to that disclosed in the paper of D.M. Bird et al (Electron. Lett., Vol. 30, No. 13, pp. 1115-1116, 1994). This light-emitting section 310d can be regarded as a kind of distribution Bragg reflector (DBR) type semiconductor laser.

The Fabry-Perot type semiconductor laser 388 has a light-reflecting surface 386 with a high reflectance and a light-emitting surface 387 with a low reflectance respectively at both ends thereof, whereby light having a wavelength width of about 30 nm is emitted from the light-emitting surface 387. The lens 375 converges the output laser light of the semiconductor laser 380 and makes thus converged light incident on the optical fiber 384, thereby connecting the semiconductor laser 388 to the optical fiber 384 in terms of optical power. The light advancing through the optical fiber 384 reaches the diffraction grating 385. The diffraction grating 385 reflects, of the light included in the oscillation wavelength width of the semiconductor laser 388, only the light component having a wavelength width of about 20 nm or less whose center is a predetermined wavelength. Thus reflected light is made incident on the semiconductor laser 388 by way of the lens 375. The incident light advances through the semiconductor laser 388, while causing stimulated emission, and reaches the light-reflecting surface 386, where it is then reflected. Thus reflected light advances through the semiconductor 388, while causing stimulated emission, and emitted from the light-emitting surface 387 so as to be reflected by the diffraction grating 385 again. Thus, the light is amplified as reflection is repeated between the diffraction grating 385 and the light-reflecting surface 386, thereby finally causing laser oscillation. This is inspection light output from the light-emitting section 310d. This inspection light is transmitted through the diffraction grating 385 and made incident on the optical fiber 321.

The light causing laser oscillation between the diffraction grating 385 and the light-reflecting surface 386 is limited to wavelength light which is reflected with a relatively high reflectance by the diffraction grating 385. Accordingly, when the diffraction grating 385 having an appropriate reflection wavelength width is used, the wavelength width of the output inspection light from the light-emitting section 310d becomes about 20 nm or less. Since the diffraction grating 385 having a narrow reflection wavelength width can be made easily, inspection light having a wavelength width of 5 nm or less can be easily realized in accordance with the light-emitting section 310d.

Here, since the light-emitting section 310d outputs inspection laser light according to laser oscillation between the diffraction grating 385 and the light-reflecting surface 386, it is not always necessary for the light-emitting section 310d to effect laser oscillation at the semiconductor laser 388.

From the invention thus described, it will be obvious that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended for inclusion within the scope of the following claims.

The basic Japanese Application No. 285068/1995 filed on November 1, 1995, No. 248255/1996 filed on September 19, 1996, No. 068390/1995 filed on March 27, 1995, No. 069554/1995 filed on March 28, 1995, and No. 182867/1995 filed on July 19, 1995 are hereby incorporated by reference.

Claims

1. A laser light source apparatus comprising:

   a semiconductor light-emitting device to be excited by a current so as to effect spontaneous emission and stimulated emission;
   a reflecting means disposed at a position opposed to a first light-emitting end face of said semiconductor light-emitting device by way of said semiconductor light-emitting device, and said reflecting means reflecting light generated by said semiconductor light-emitting device so as to make thus reflected light travel through said semiconductor light-emitting device again; and
   an optical waveguide for receiveing and guiding the light emitted from said first light-emitting end face, said optical waveguide comprising a reflecting area which selectively reflects a part of the light emitted from the first light-emitting end face of said semiconductor light-emitting device, a core of said reflecting area comprising a first diffraction grating disposed in a first area, refractive index of said first diffraction grating changing periodically along an optical-axis direction, and said first diffraction grating selectively reflecting, of the light emitted from the first light-emitting end face of said semiconductor light-emitting device, a part of the light within a first wavelength range,
   said reflecting means, said semiconductor light-emitting device, and said diffraction grating constituting a laser resonator.

2. A laser light source apparatus according to claim 1, wherein said reflecting means is a reflectively proc-

essed end face of said semiconductor light-emitting device opposed to said first light-emitting end face.

3. A laser light source apparatus according to claim 1, wherein said reflecting means is a reflector reflecting light emitted from a second light-emitting end face of said semiconductor light-emitting device.

4. A laser light source apparatus according to claim 1, further comprising a period changing means for changing grating period of change in refractive index along the optical-axis direction in said first diffraction grating.

5. A laser light source apparatus according to claim 4, wherein said period changing means is a stress applying means which applies a stress to a part of said optical waveguide including said first diffraction grating along the optical-axis direction.

6. A laser light source apparatus according to claim 4, wherein said period changing means is a temperature adjusting means for changing temperature at a part of said optical waveguide including said first diffraction grating.

7. A laser light source apparatus according to claim 4, wherein said period changing means changes said grating period with time.

8. A laser light source apparatus according to claim 7, wherein changing width in reflection wavelength as said grating period is changed with time is 1 nm or greater.

9. A laser light source apparatus according to claim 7, wherein changing width in reflection wavelength as said grating period is changed with time is 20 nm or less.

10. A laser light source apparatus according to claim 9, wherein changing width in reflection wavelength as said grating period is changed with time is at least 2 nm but not greater than 10 nm.

11. A laser light source apparatus according to claim 1, further comprising a current driving means for supplying, to said semiconductor light-emitting device, a stabilizing current having a level not lower than a threshold current level for oscillation of said laser oscillator and a pulse current required for generating pulse laser light.

12. A laser light source apparatus according to claim 11, wherein said current driving means comprises:

a first current source for supplying said stabilizing current;
a second current source for supplying said pulse current; and
a current adder for adding said stabilizing current and said pulse current together.

13. A laser light source apparatus according to claim 11, wherein said current driving means always supplies a current having a level not lower than that of said stabilizing current at least except for a time during which said pulse current is supplied.

14. A laser light source apparatus according to claim 11, wherein said current driving means supplies said stabilizing current over a predetermined period of time before said pulse current is supplied.

15. A laser light source apparatus according to claim 14, wherein said predetermined period is a time during which light travels to-and-fro through said laser resonator for once to 200 times.

16. A laser light source apparatus according to claim 11, wherein said pulse current has a peak current level which is at least 10 times as high as the current level of said stabilizing current.

17. A laser light source apparatus according to claim 1, wherein said first wavelength range has a width of 1 nm or greater.

18. A laser light source apparatus according to claim 17, wherein said first wavelength range has a width of 20 nm or less.

19. A laser light source apparatus according to claim 18, wherein said first wavelength range has a width of at least 2 nm but not greater than 10 nm.

20. A laser light source apparatus according to claim 17, wherein said first diffraction grating has grating period changing monotonously along said optical-axis direction.

21. A laser light source apparatus according to claim 20, wherein the grating period of said first diffraction grating on the semiconductor light-emitting device side is shorter than that on the opposite side.

22. A laser light source apparatus according to claim 20, wherein said first diffraction grating has reflectance increasing monotonously along a direction moving away from said semiconductor light-emitting device.

23. A laser light source apparatus according to claim 21, wherein said first diffraction grating has reflectance decreasing monotonously along a direction moving away from said semiconductor light-emitting device.

24. A laser light source apparatus according to claim 1, wherein said reflecting area further comprises a second diffraction grating formed in a second area of the core and refractive index of said second diffraction grating periodically changing along the optical-axis direction, and said reflecting area selectively reflecting, of the light emitted from the first light-emitting end face of said semiconductor light-emitting device, a part of the light within a second wavelength range.

25. A laser light source apparatus according to claim 24, wherein said second wavelength range has a width of 1 nm or greater.

26. A laser light source apparatus according to claim 25, wherein said second wavelength range has a width of 20 nm or less.

27. A laser light source apparatus according to claim 26, wherein said second wavelength range has a width of at least 2 nm but not greater than 10 nm.

28. A laser light source apparatus according to claim 24, wherein said second diffraction grating has grating period changing monotonously along said optical-axis direction.

29. A laser light source apparatus according to claim 28, wherein the grating period of said second diffraction grating on the semiconductor light-emitting device side is shorter than that on the opposite side.

30. A laser light source apparatus according to claim 28, wherein said second diffraction grating has reflectance increasing monotonously along a direction moving away from said semiconductor light-emitting device.

31. A laser light source apparatus according to claim 28, wherein said second. diffraction grating has reflectance decreasing monotonously along a direction moving away from said semiconductor light-emitting device.

32. A laser light source apparatus according to claim 24, wherein no common area exists between said first and second areas.

33. A laser light source apparatus according to claim 24, wherein said first and second areas have a common area.

34. An OTDR apparatus comprising:

a laser light source apparatus, said laser light source apparatus comprising:

a semiconductor light-emitting device to be excited by a current to effect spontaneous emission and stimulated emission,

a reflecting means disposed at a position opposed to a first light-emitting end face of said semiconductor light-emitting device by way of said semiconductor light-emitting device, and said refrecting means reflecting light generated by said semiconductor light-emitting device so as to make thus reflected light travel through said semiconductor light-emitting device again, and

an optical waveguide for receiving and guiding the light emitted from said first light emitting end face, said optical waveguide comprising a reflecting area reflecting a part of the light emitted from said first light-emitting end face of the semiconductor light-emitting device, and a core of said reflecting area comprising a first diffraction grating disposed in a first area, refractive index of said first diffraction grating changing periodically along an optical-axis direction, and said first diffraction grating selectively reflecting, of the light emitted from the first light-emitting end face of said semiconductor light-emitting device, a partof light within a first wavelength range,

said reflecting means, said semiconductor light-emitting device, and said diffraction grating constituting a laser resonator;

an optical path setting device for receiving, from a first terminal, the light emitted from said laser light source apparatus and sending, from a second terminal, thus received light toward an optical fiber to be measured, and also receiveing, from the second terminal, return light from the optical fiber and sending, from a third terminal, thus received return light; and

an optical measurement section for measuring intensity in the light output from the third terminal of said optical path setting device.

35. An OTDR apparatus according to claim 34, wherein said optical path setting device is an optical coupler.

36. An OTDR apparatus according to claim 34, wherein said optical path setting device is an optical directional coupler.

37. An OTDR apparatus according to claim 34, further comprising a band pass filter in an optical path between said laser light source apparatus and said optical fiber to be measured.

38. An OTDR apparatus according to claim 34, wherein said reflecting means is a reflectively processed end face of said semiconductor light-emitting

device opposed to said first light-emitting end face.

39. An OTDR apparatus according to claim 34, wherein said reflecting means is a reflector reflecting light emitted from a second light-emitting end face of said semiconductor light-emitting device.

40. An OTDR apparatus according to claim 34, further comprising a period changing means for changing grating period of change in refractive index along said optical-axis direction in said first diffraction grating.

41. An OTDR apparatus according to claim 40, wherein said period changing means is a stress applying means for applying a stress to a part of said optical waveguide including said first diffraction grating along said optical-axis direction.

42. An OTDR apparatus according to claim 40, wherein said period changing means is a temperature adjusting means changing temperature at a part of said optical waveguide including said first diffraction grating.

43. An OTDR apparatus according to claim 40, wherein said period changing means changes said grating period with time.

44. An OTDR apparatus according to claim 43, wherein changing width in reflection wavelength as said grating period is changed with time is 1 nm or greater.

45. An OTDR apparatus according to claim 44, wherein changing width in reflection wavelength as said grating period is changed with time is 20 nm or less.

46. An OTDR apparatus according to claim 45, wherein changing width in reflection wavelength as said grating period is changed with time is at least 2 nm but not greater than 10 nm.

47. An OTDR apparatus according to claim 34, further comprising a current driving means for supplying, to said semiconductor light-emitting device, a stabilizing current having a level not lower than a threshold current level for oscillation of said laser oscillator and a pulse current required for generating pulse laser light.

48. An OTDR apparatus according to claim 47, wherein said current driving means comprises:

a first current source for supplying said stabilizing current;
a second current source for supplying said pulse current; and
a current adder for adding said stabilizing current and said pulse current together.

49. An OTDR apparatus according to claim 47, wherein said current driving means always supplies a current having a level not lower than that of said stabilizing current at least except for a time during which said pulse current is supplied.

50. An OTDR apparatus according to claim 47, wherein said current driving means supplies said stabilizing current over a predetermined period of time before said pulse current is supplied.

51. An OTDR apparatus according to claim 50, wherein said predetermined period is a time during which light travels to-and-fro through said laser resonator for once to 200 times.

52. An OTDR apparatus according to claim 47, wherein said pulse current has a peak current level which is at least 10 times as high as the current level of said stabilizing current.

53. An OTDR apparatus according to claim 47, wherein said optical measurement section further comprises a high pass filter which eliminates a low frequency component of input optical intensity.

54. An OTDR apparatus according to claim 34, wherein said first wavelength range has a width of 1 nm or greater.

55. An OTDR apparatus according to claim 54, wherein said first wavelength range has a width of 20 nm or less.

56. An OTDR apparatus according to claim 55, wherein said first wavelength range has a width of at least 2 nm but not greater than 10 nm.

57. An OTDR apparatus according to claim 53, wherein said first diffraction grating has grating period changig monotonously along said optical-axis direction.

58. An OTDR apparatus according to claim 57, wherein the grating period of said first diffraction grating on the semiconductor light-emitting device side is shorter than that on the opposite side.

59. An OTDR apparatus according to claim 57, wherein said first diffraction grating has reflectance increasing monotonously along a direction moving away from said semiconductor light-emitting device.

60. An OTDR apparatus according to claim 58, wherein said first diffraction grating has reflectance decreasing monotonously along a direction moving away from said semiconductor light-emitting device.

61. An OTDR apparatus according to claim 34, wherein said reflecting area further comprises a second diffraction grating formed in a second area of the core, refractive index of said second diffraction grating changing periodically along the optical-axis direction, said reflecting area selectively reflecting, of the light emitted from the first light-emitting end face of said semiconductor light-emitting device, a part of the light within a second wavelength range.

62. An OTDR apparatus according to claim 61, wherein said second wavelength range has a width of 1 nm or greater.

63. An OTDR apparatus according to claim 62, wherein said second wavelength range has a width of 20 nm or less.

64. An OTDR apparatus according to claim 63, wherein said second wavelength range has a width of at least 2 nm but not greater than 10 nm.

65. An OTDR apparatus according to claim 61, wherein said second diffraction grating has grating period changing monotonously along said optical-axis direction.

66. An OTDR apparatus according to claim 65, wherein the grating period of said second diffraction grating on the semiconductor light-emitting device side is shorter than that on the opposite side.

67. An OTDR apparatus according to claim 65, wherein said second diffraction grating has reflectance increasing monotonously along a direction moving away from said semiconductor light-emitting device.

68. An OTDR apparatus according to claim 66, wherein said second diffraction grating has reflectance decreasing monotonously along a direction moving away from said semiconductor light-emitting device.

69. An OTDR apparatus according to claim 61, wherein no common area exists between said first and second areas.

70. An OTDR apparatus according to claim 61, wherein said first and second areas have a common area.

71. An optical communication line inspection system for inspecting transmission state of an optical communication line for transmitting signal light, said system comprising:

a light-emitting section for outputting inspection light with a wavelength in a first wavelength range;
an optical path setting section disposed in an optical path of said optical communication line, said optical path setting section receiving the inspection light output from said light-emitting section and introducing thus received inspection light into said optical communication line, and also receiving return light derived from the inspection light input from said optical communication line and outputing thus received return light to a path different from said optical communication line;
a waveguide type reflecting means disposed at a terminating portion of said optical communication line, said reflecting means reflecting light with a wavelength in a second wavelength range including said first wavelength range, said reflecting means comprising a first diffraction grating, refractive index of a core thereof changing periodically along an optical-axis direction;
an optical measurement section for measuring intensity in the return light output from said optical path setting section; and
a processing section for determining, based on a result of the measurement by said optical measurement section, the transmission state of said optical communication line.

72. An optical communication line inspection system according to claim 71, wherein said first wavelength width has a width of 20 nm or less.

73. An optical communication line inspection system according to claim 71, wherein said first wavelength width has a width of 5 nm or less.

74. An optical communication line inspection system according to claim 71, wherein said light-emitting section comprises a laser light source apparatus, said laser light source apparatus comprising:

a semiconductor light-emitting device to be excited by a current so as to effect spontaneous emission and stimulated emission;
a reflecting means disposed at a position opposed to a first light-emitting end face of said semiconductor light-emitting device by way of said semiconductor light-emitting device, and said reflecting means reflecting light generated by said semiconductor light-emitting device so as to make thus reflected light travel through said semiconductor light-emitting device again; and
an optical waveguide for receiving and guiding the light emitted from said first light-emitting end face, said optical waveguide comprising a reflecting area reflecting selectively at least a part of the light emitted from the first light-emitting end face of said semiconductor light-emitting device, a core of said reflecting area comprising a second diffraction grating, refrac-

tive index of said second diffraction grating changing periodically along the optical-axis direction,

said reflecting means, said semiconductor light-emitting device, and said third diffraction grating constituting a laser resonator.

75. An optical communication line inspection system according to claim 74, wherein said reflecting area further comprises a third diffraction grating which reflects wavelength light having a wavelength range different from reflection wavelength range of said second diffraction grating.

76. An optical communication line inspection system according to claim 71, wherein said light-emitting section comprises a distribued feedback type semiconductor laser.

77. An optical communication line inspection system according to claim 71, further comprising a band pass filter in an optical path between said laser light-emitting section and said optical communication line.

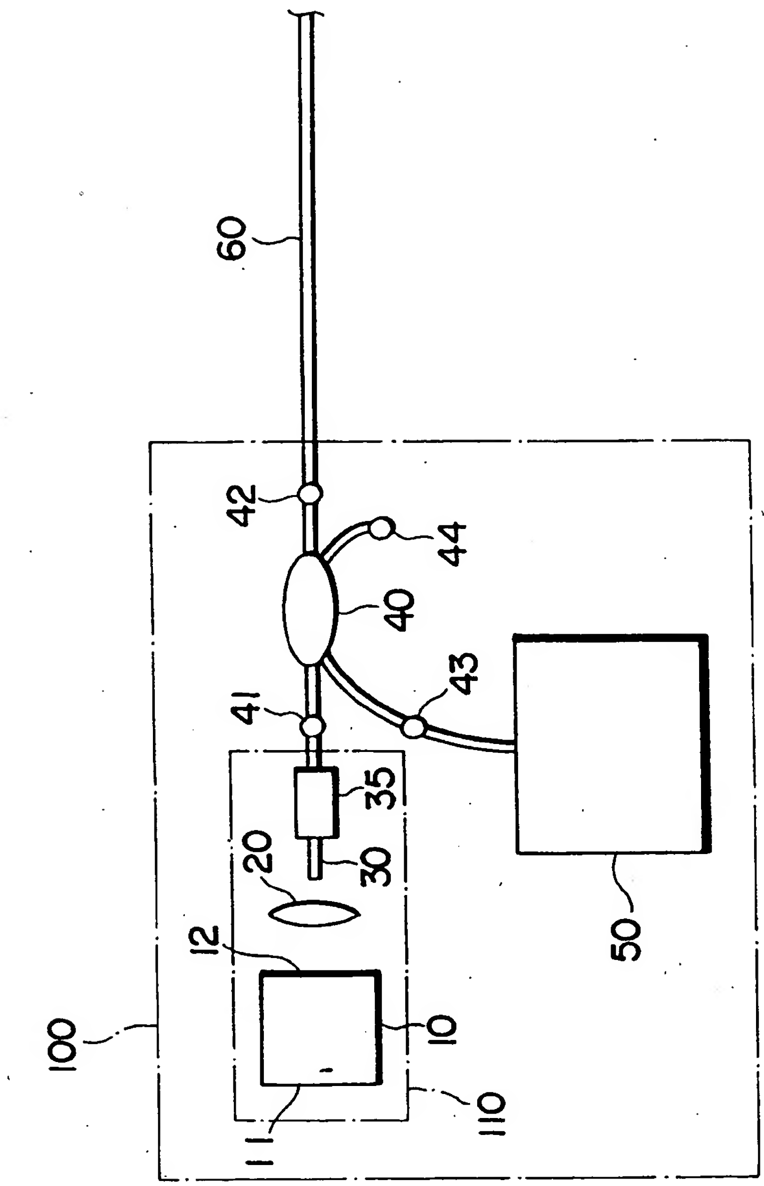


Fig. 1

Fig.2

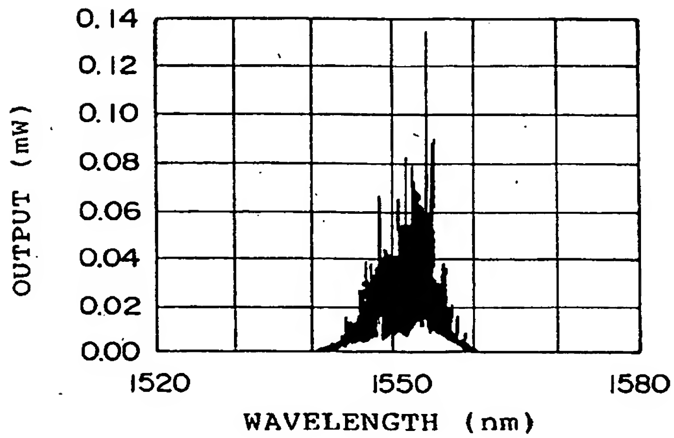


Fig.3

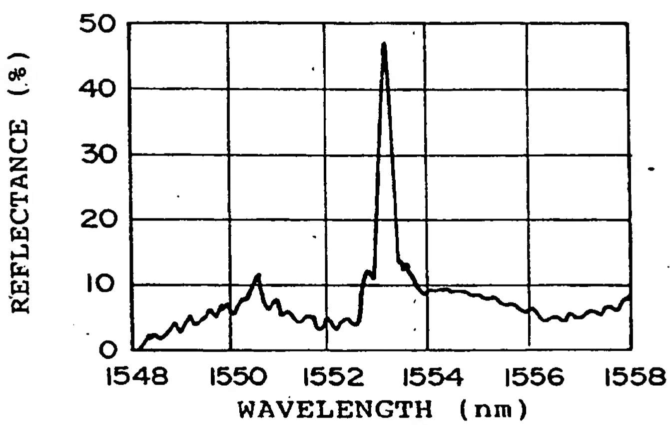


Fig.4

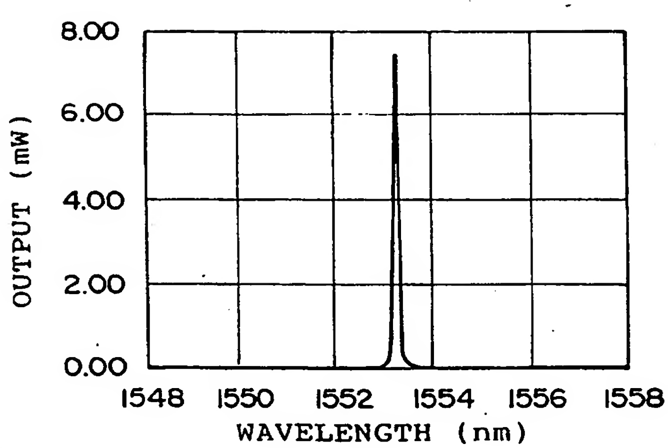


Fig. 5

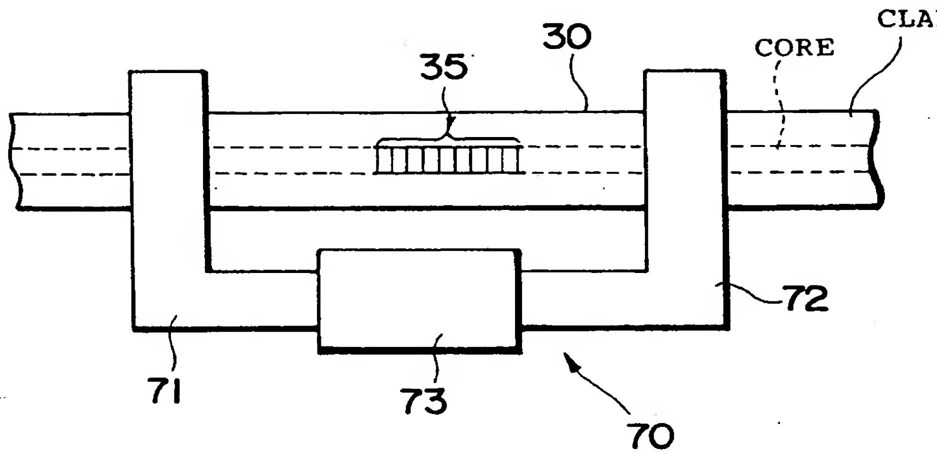


Fig. 6

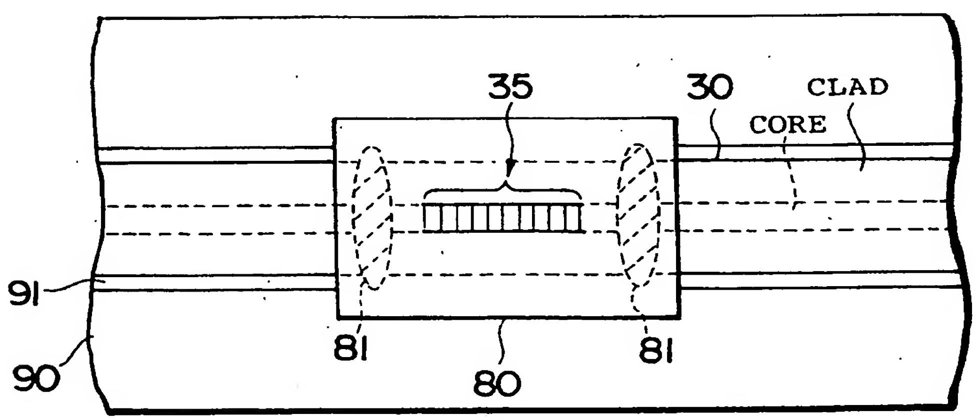


Fig. 7

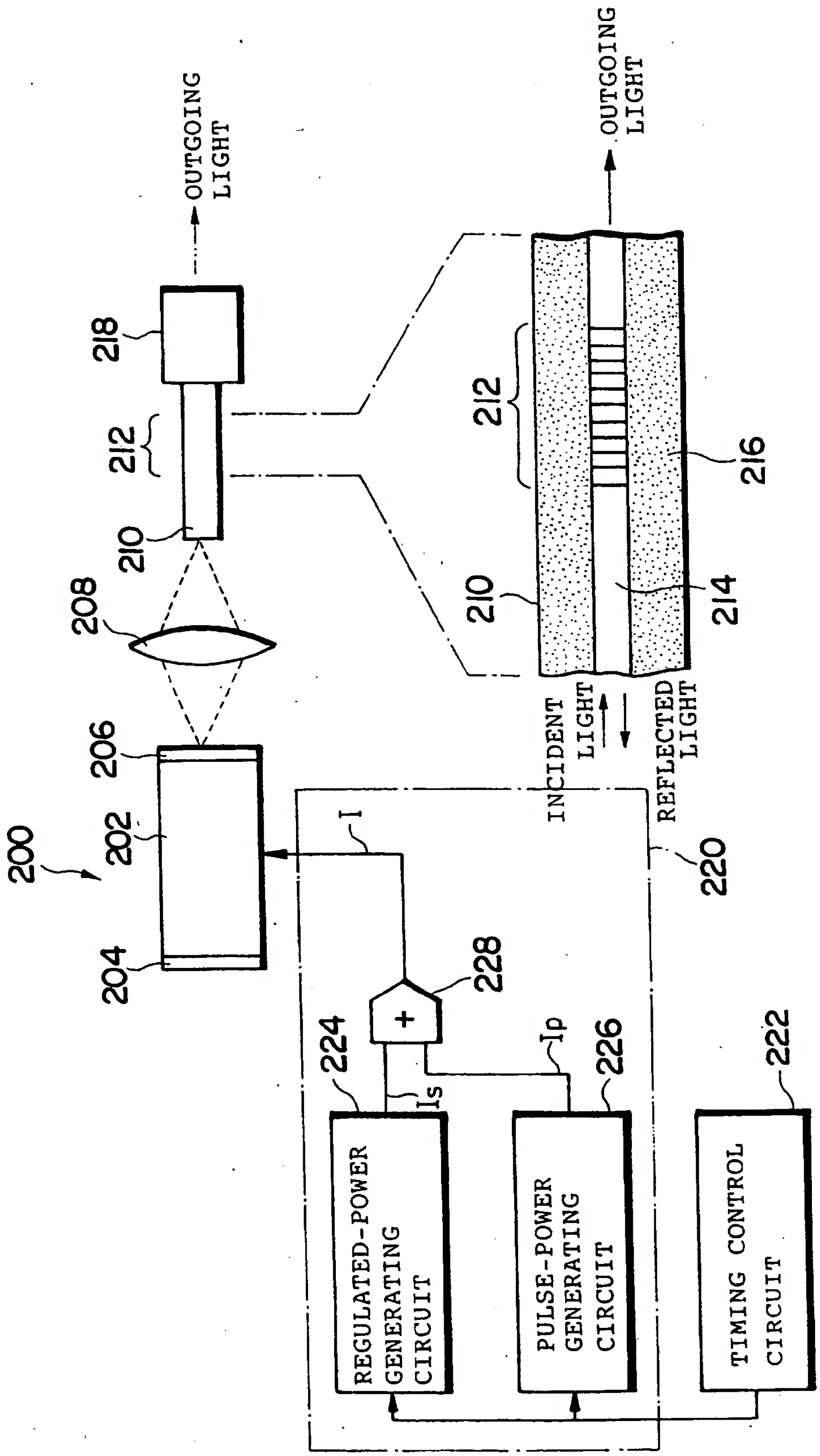

200
202
204
206
208
210
212
218
OUTGOING LIGHT
212
210
214
216
OUTGOING LIGHT
INCIDENT LIGHT
REFLECTED LIGHT
220
I
228
Is
Ip
224
226
222
REGULATED-POWER GENERATING CIRCUIT
PULSE-POWER GENERATING CIRCUIT
TIMING CONTROL CIRCUIT

Fig. 8

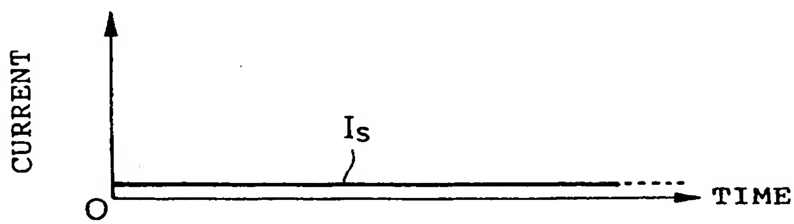


Fig. 9

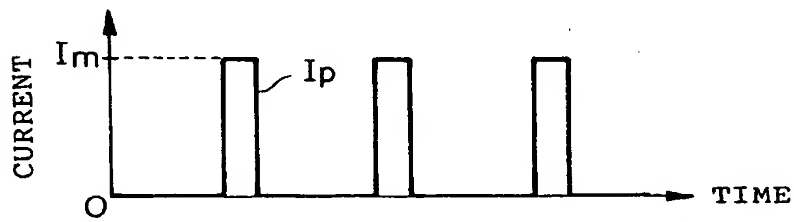


Fig. 10

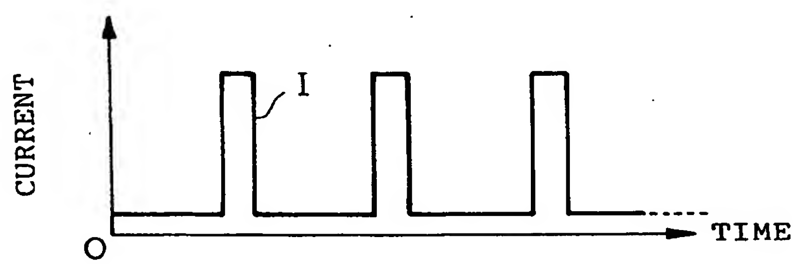


Fig. 11

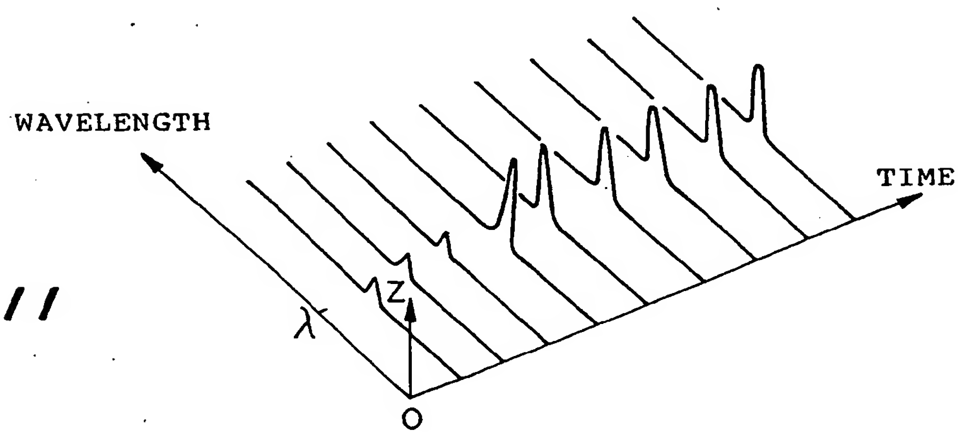


Fig. 12

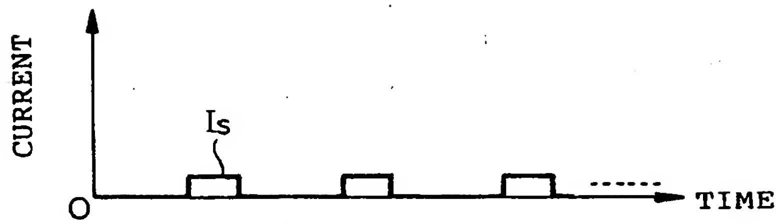


Fig. 13

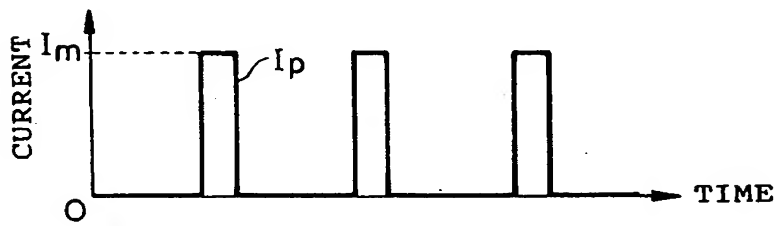


Fig. 14

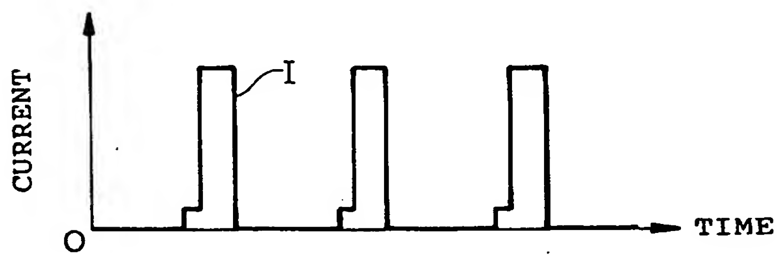


Fig. 15

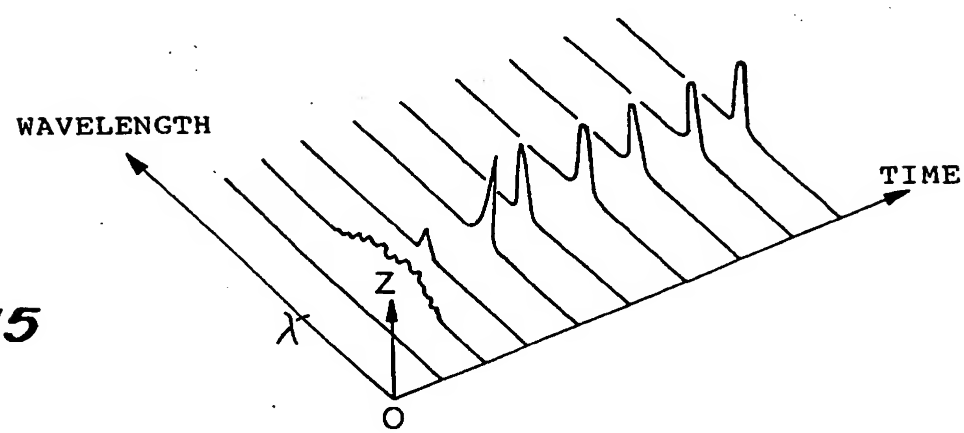


Fig. 16

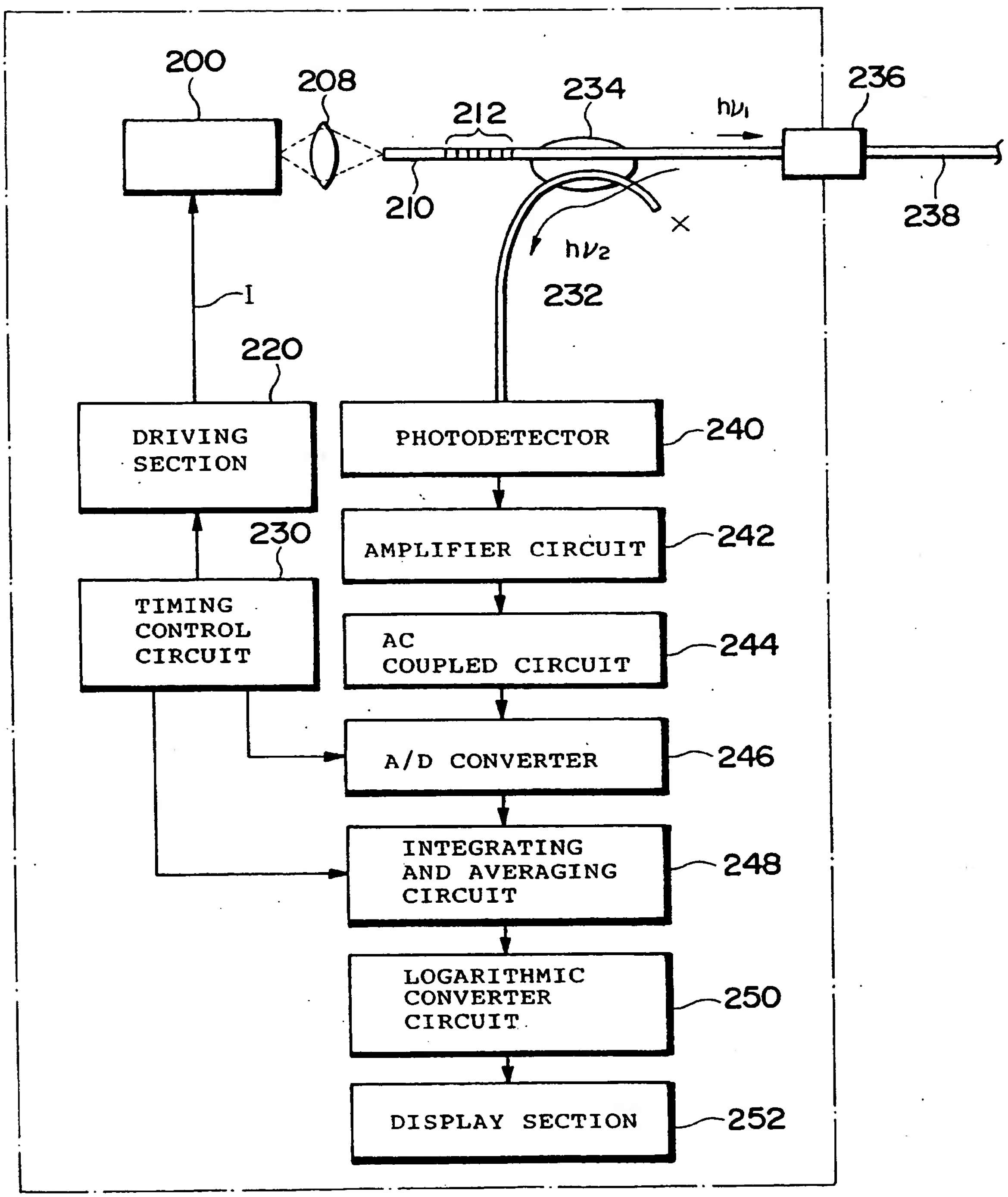

200
208
212
234
236
hν1
210
238
×
hν2
232
I
220
DRIVING SECTION
PHOTODETECTOR
240
AMPLIFIER CIRCUIT
242
230
TIMING CONTROL CIRCUIT
AC COUPLED CIRCUIT
244
A/D CONVERTER
246
INTEGRATING AND AVERAGING CIRCUIT
248
LOGARITHMIC CONVERTER CIRCUIT
250
DISPLAY SECTION
252

Fig. 17

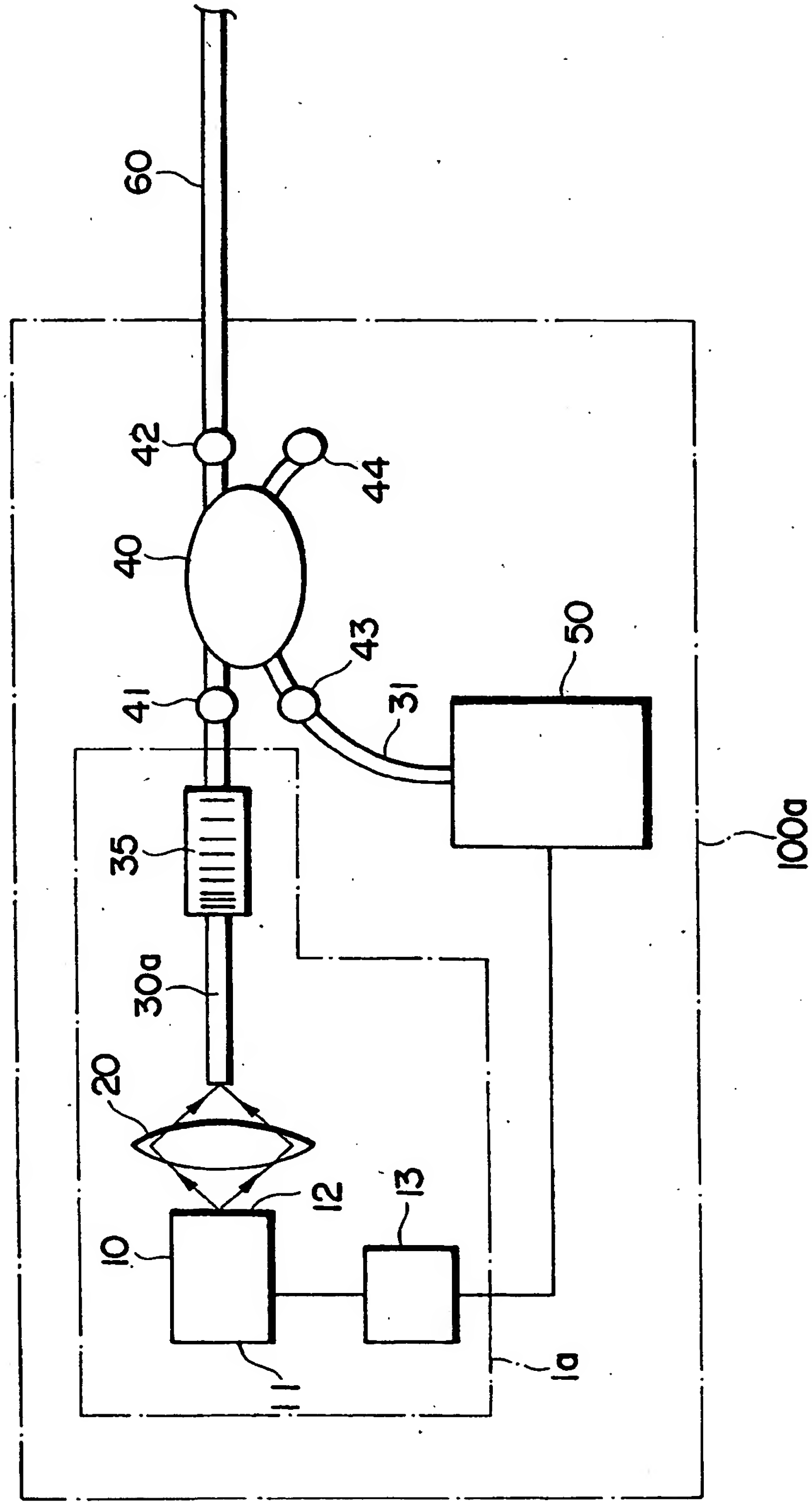


Fig. 18

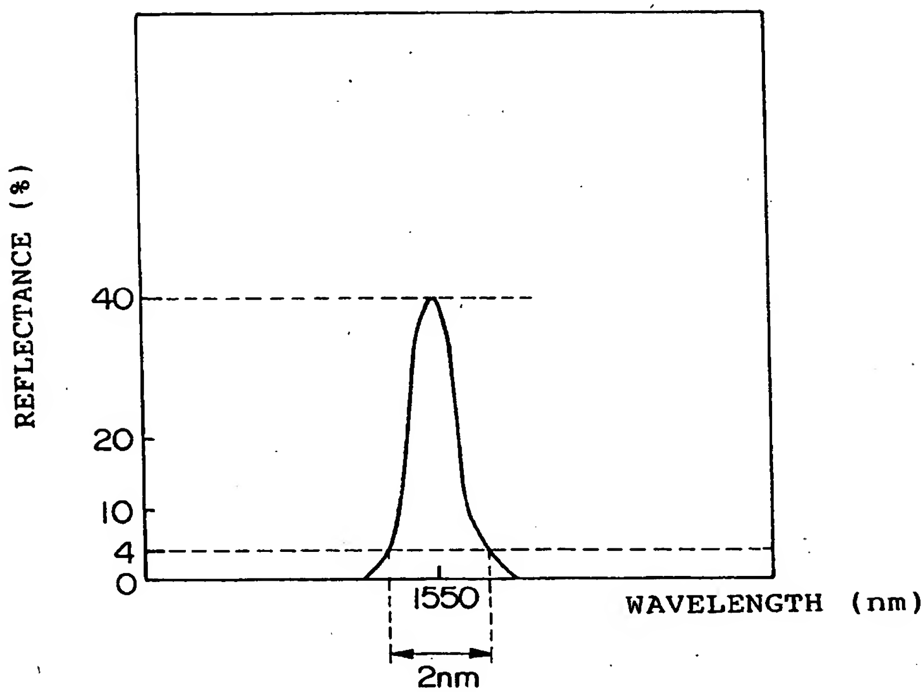
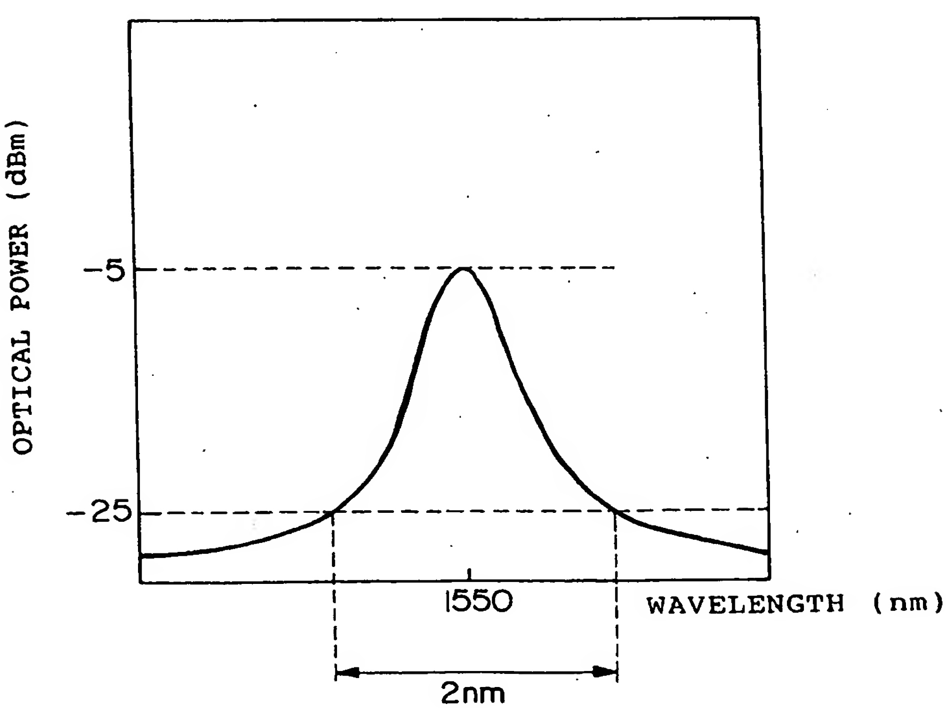

REFLECTANCE (%)
40
20
10
4
0
1550
WAVELENGTH (nm)
2nm

Fig. 19


OPTICAL POWER (dBm)
-5
-25
1550
WAVELENGTH (nm)
2nm

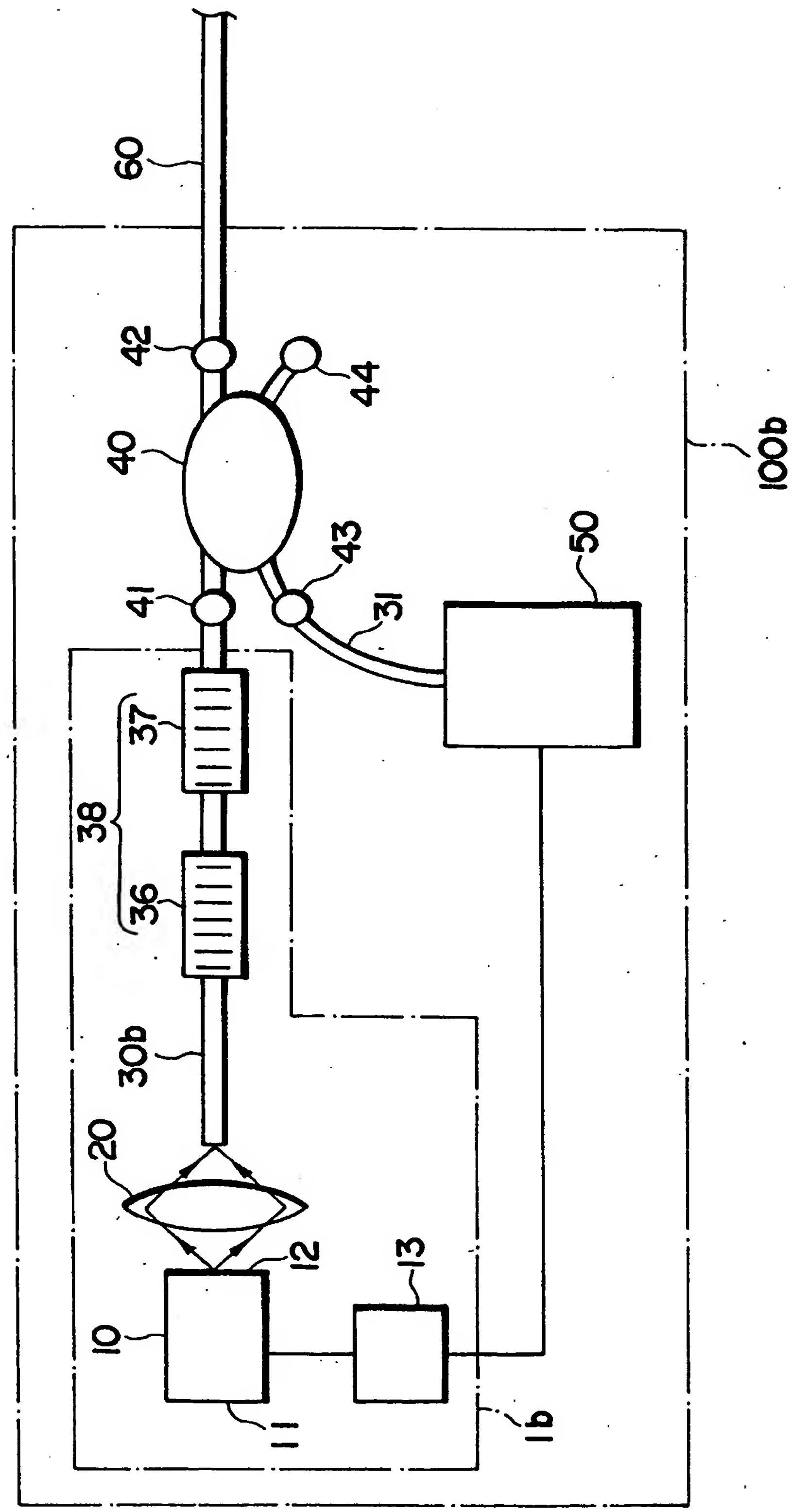


Fig.20

Fig.21

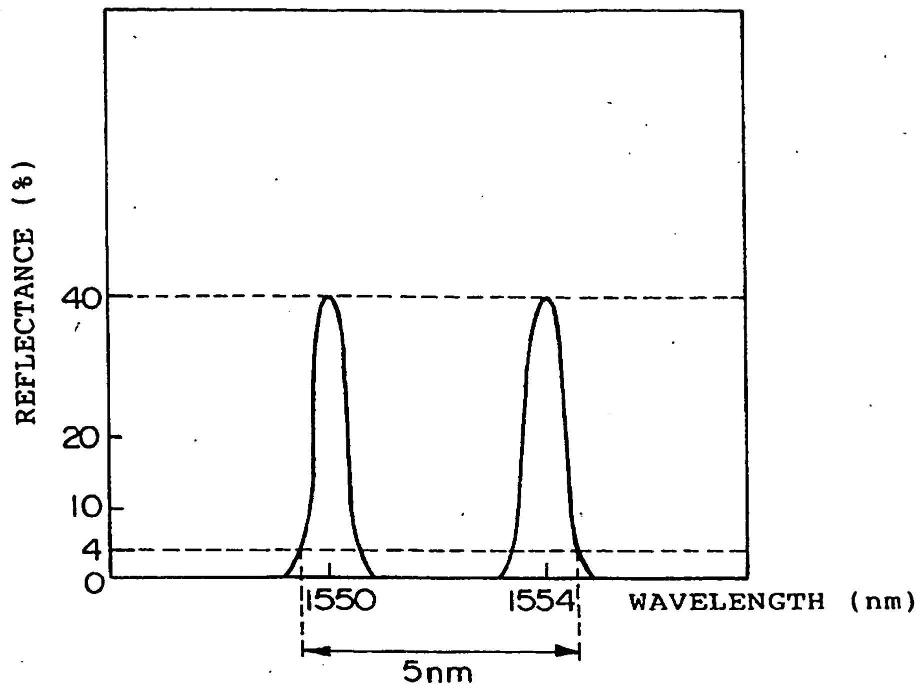

REFLECTANCE (%)
40
20
10
4
0
1550
1554
WAVELENGTH (nm)
5nm

Fig.22

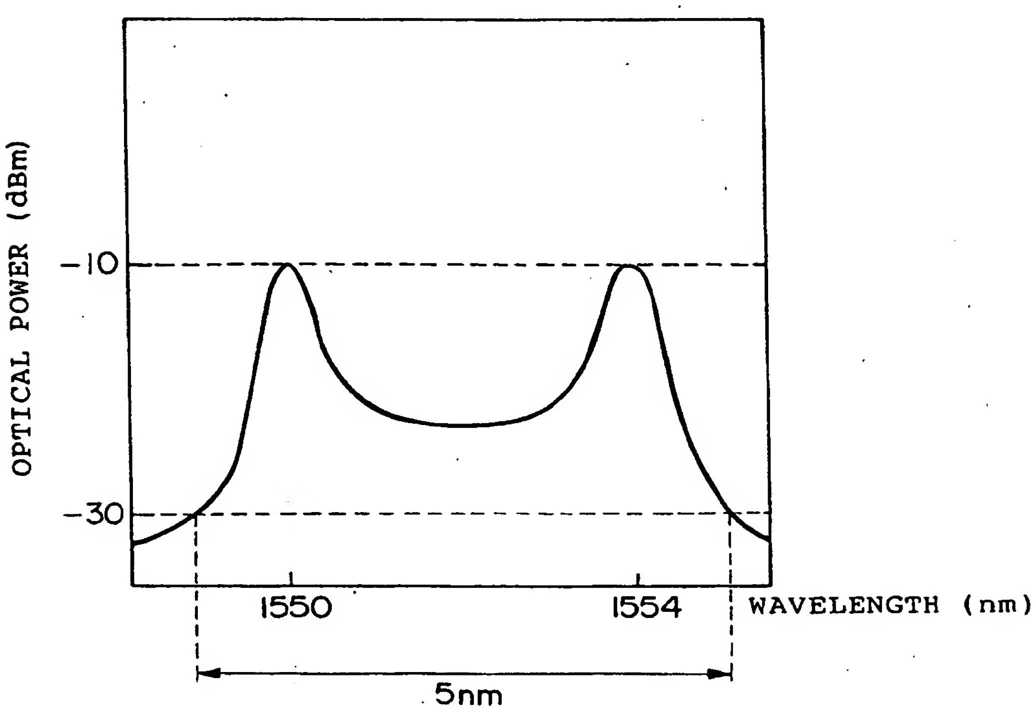
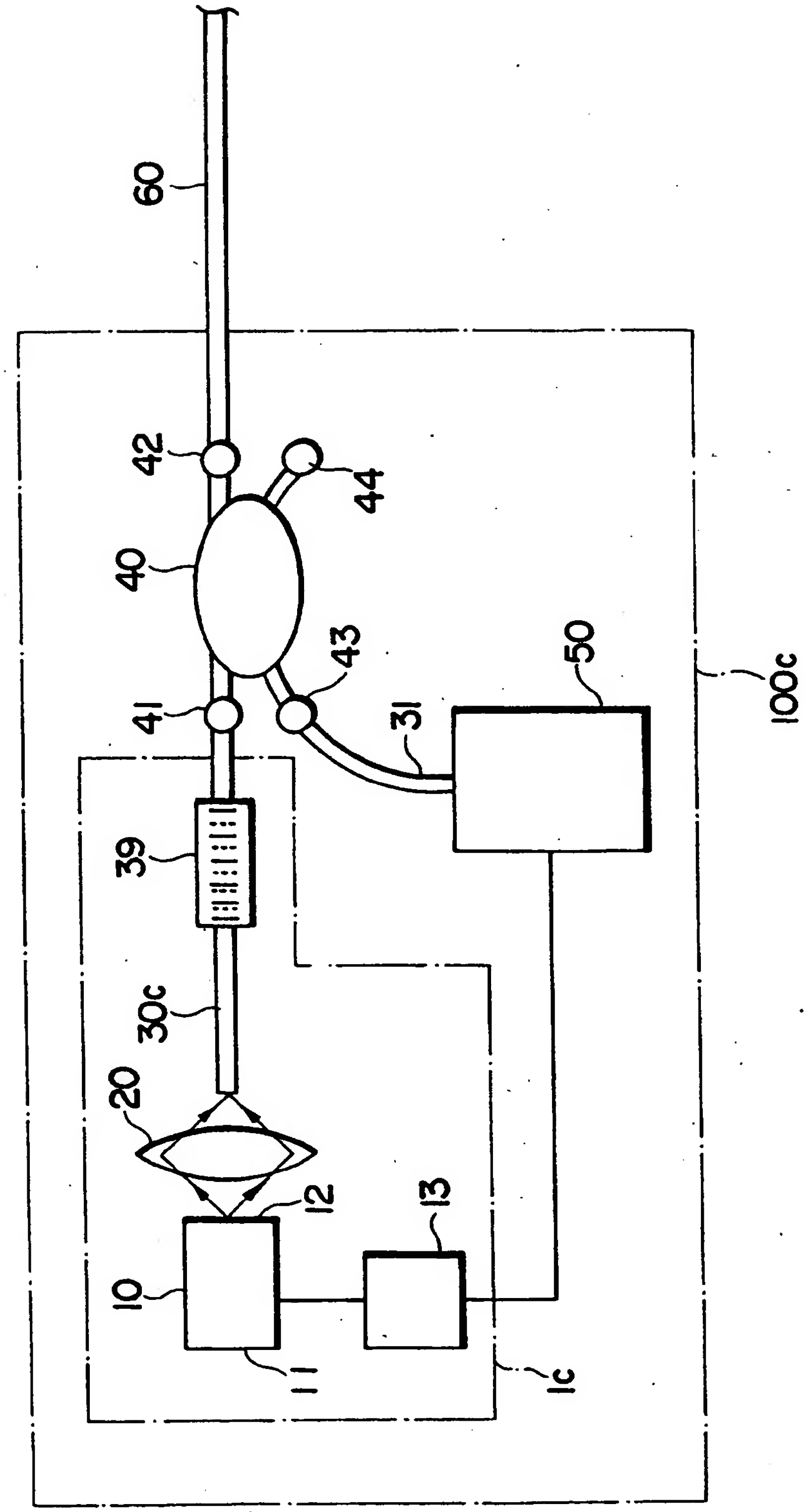

OPTICAL POWER (dBm)
-10
-30
1550
1554
WAVELENGTH (nm)
5nm

Fig.23



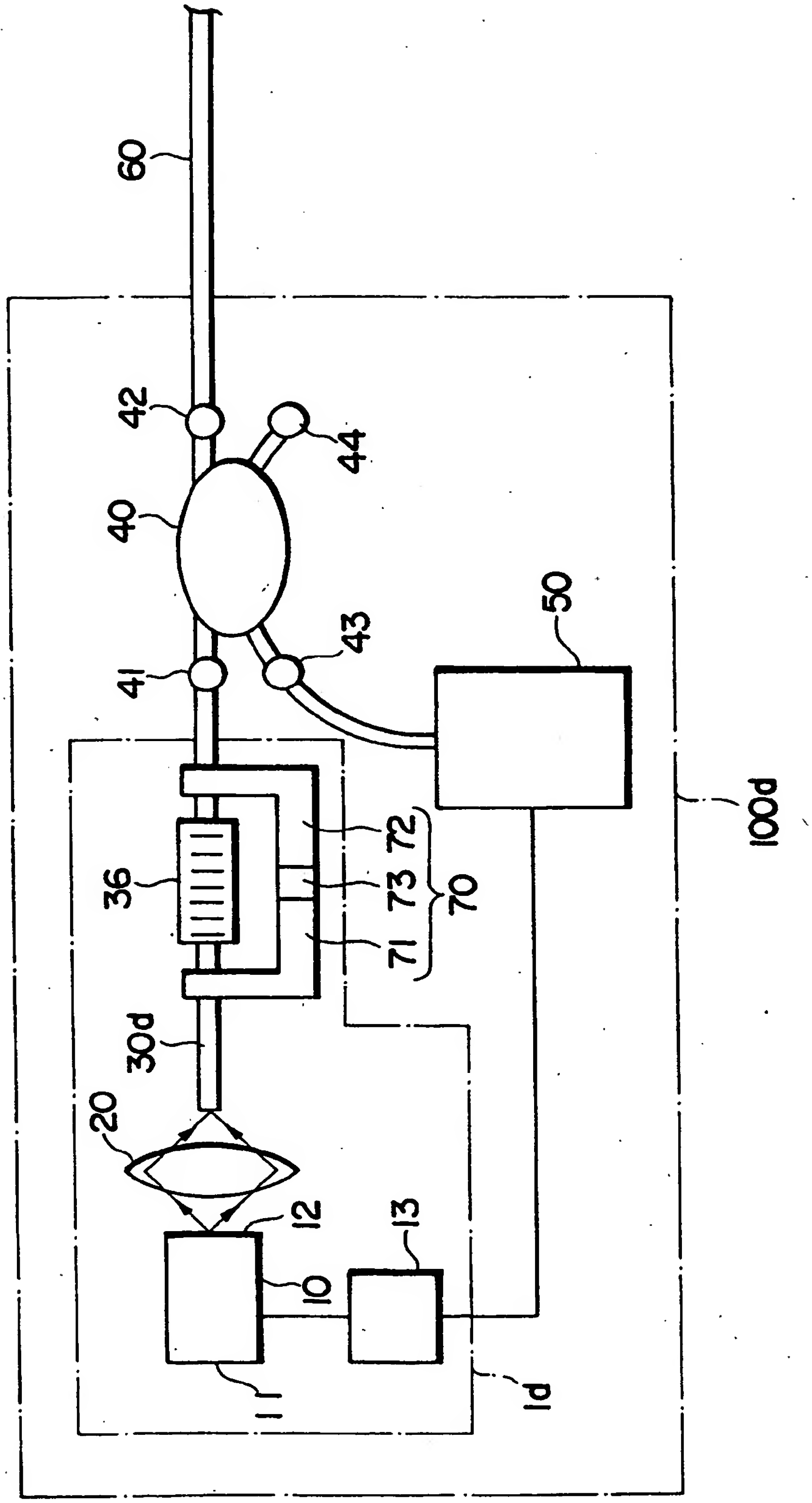
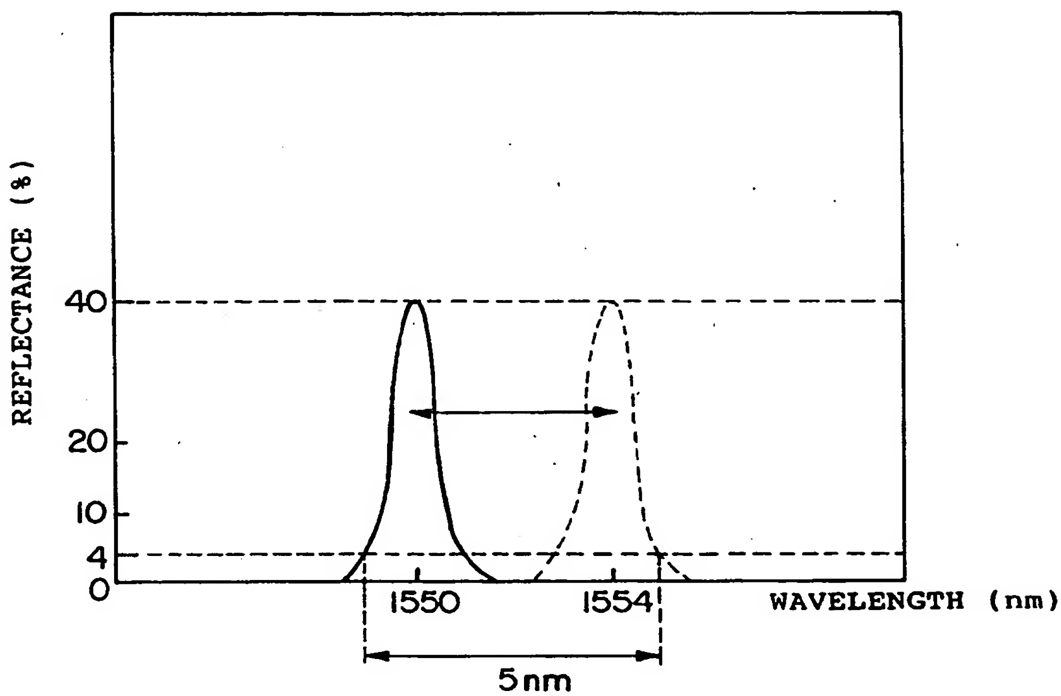


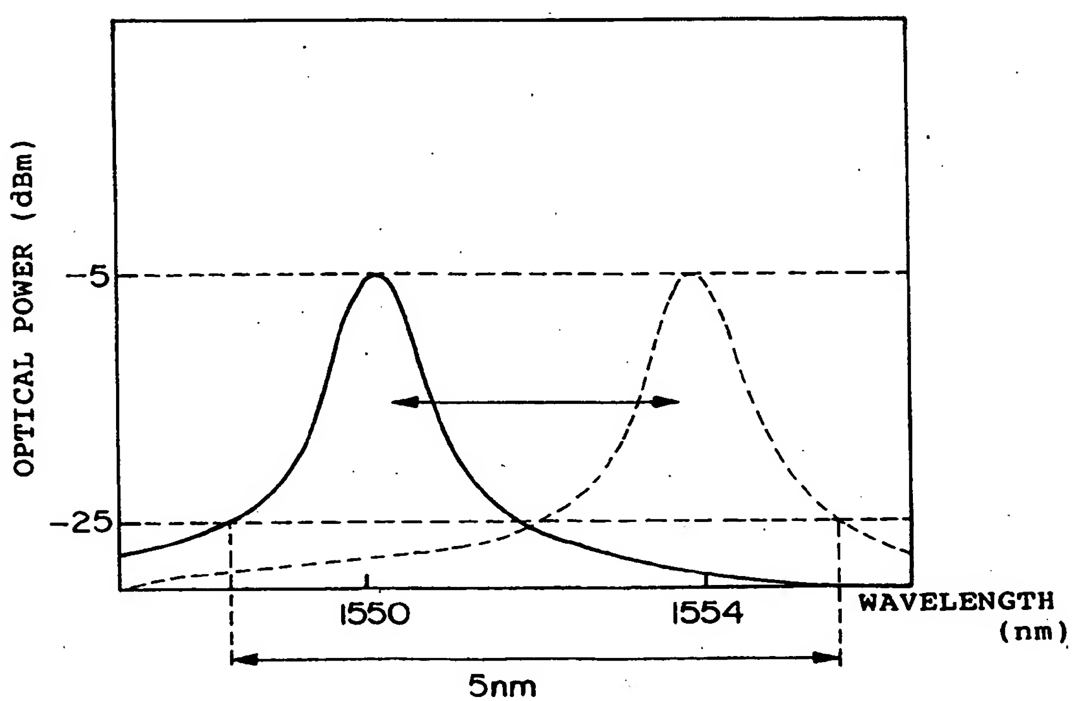
Fig.24

Fig.25



REFLECTANCE (%)
40
20
10
4
0
1550
1554
WAVELENGTH (nm)
5nm

Fig.26



OPTICAL POWER (dBm)
-5
-25
1550
1554
WAVELENGTH (nm)
5nm

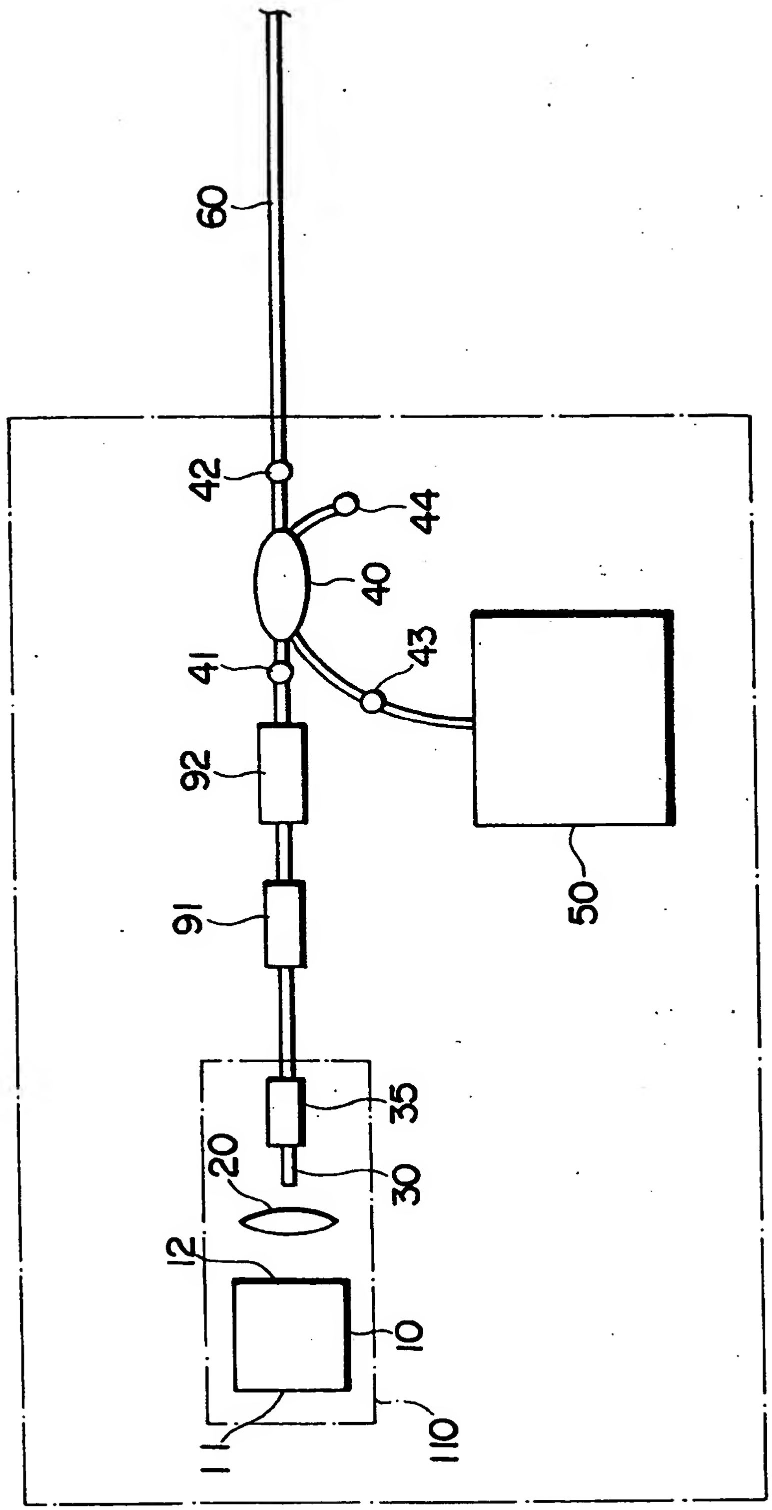
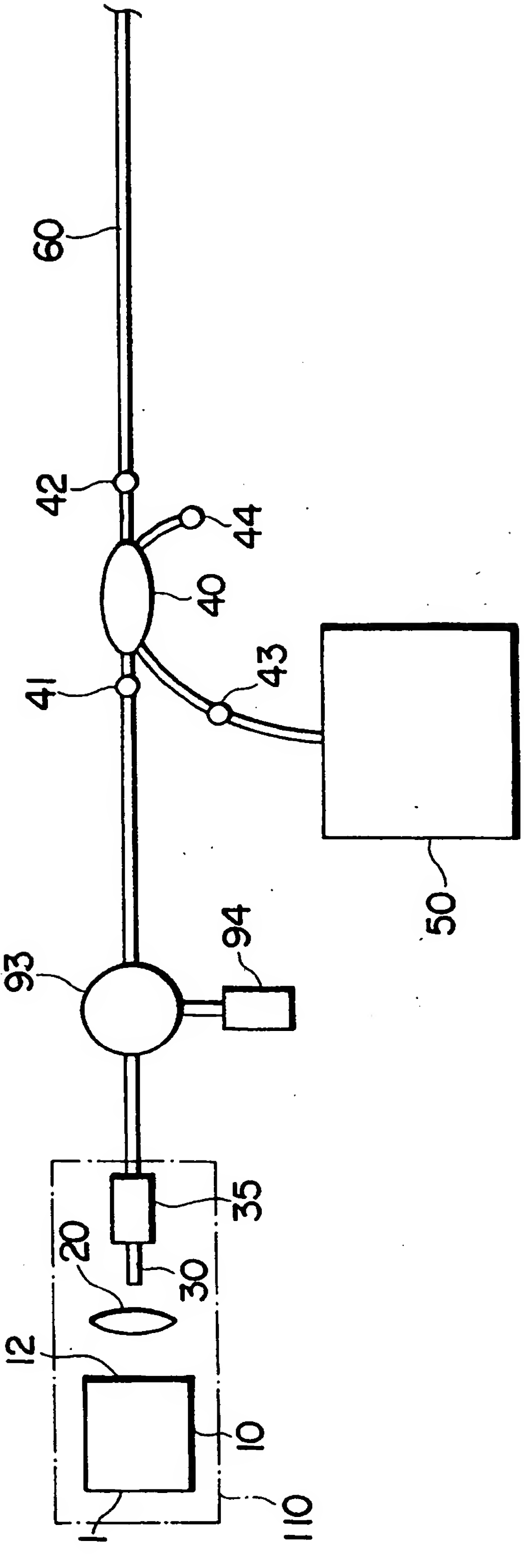


Fig.27

Fig. 28



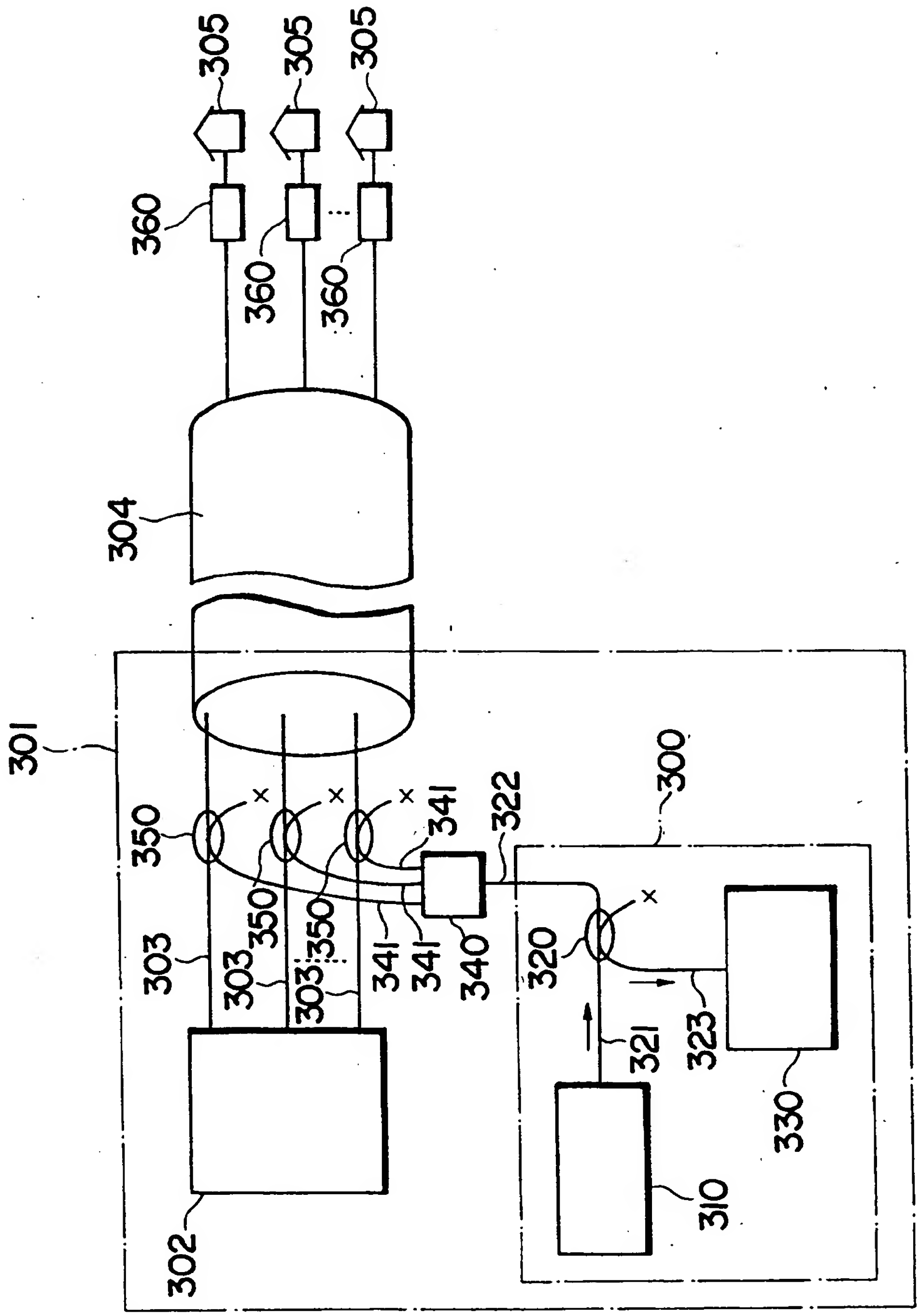

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Fig.29

Fig. 30

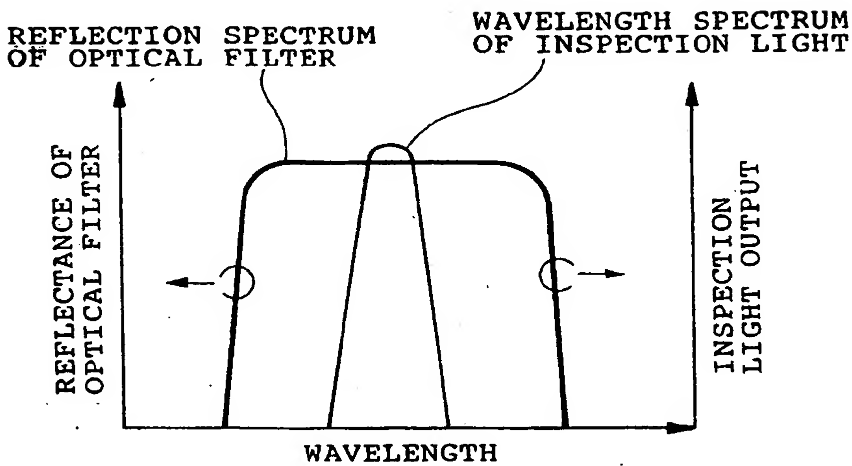


Fig. 31

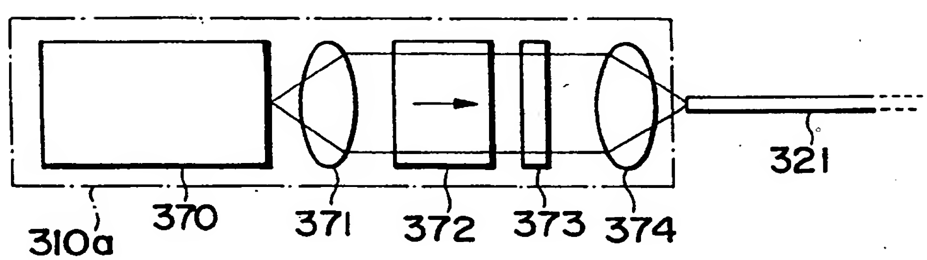


Fig. 32

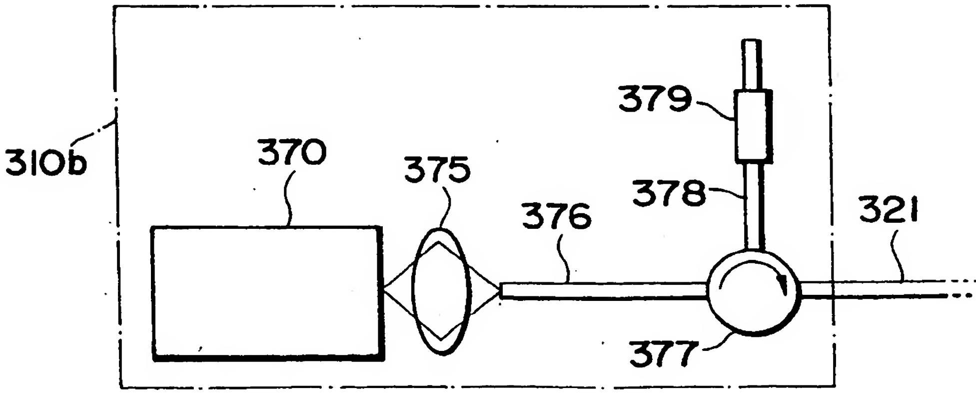


Fig.33

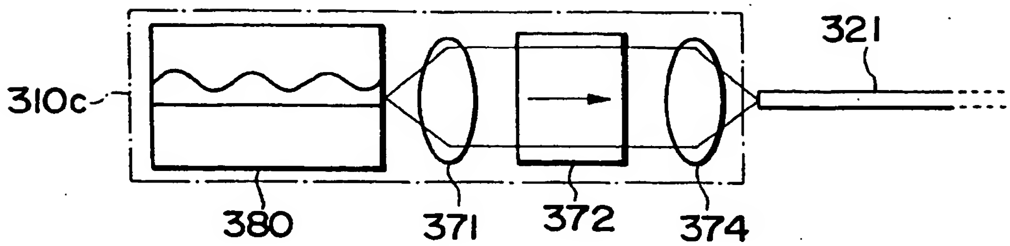
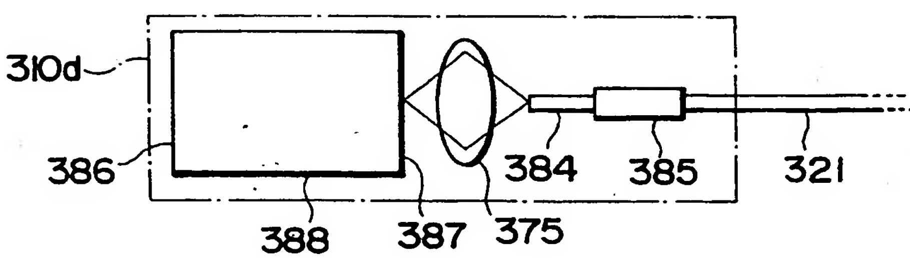


Fig.34



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 11 5368

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	IEEE PHOTONICS TECHNOLOGY LETTERS, vol. 5, no. 1, 1 January 1993, pages 28-31, XP000335389 MORTON P A: "MODE-LOCKED HYBRID SOLITON PULSE SOURCE WITH EXTREMELY WIDE OPERATING FREQUENCY RANGE"	1-4,6	H01S3/085 G01M11/00 H04B10/08
A		7-15,17, 22, 38-40, 42-51, 54-59, 72-74	

X	LASER FOCUS WORLD, vol. 29, no. 1, 1 January 1993, page 20, 22 XP000344891 JUNGBLUTH E D: "FIBER BRAGG GRATING TUNES LASER DIODES"	1-5, 17-19	
Y	* the whole document *	34,35, 38-41, 54-56, 71-74	TECHNICAL FIELDS SEARCHED (Int.Cl.6)

D,X	ELECTRONICS LETTERS, vol. 27, no. 13, 20 June 1991, pages 1115-1116, XP000238670 BIRD D M: "NARROW LINE SEMICONDUCTOR LASER USING FIBRE GRATING" * the whole document *	1-3	H01S G01M H04B

A	PATENT ABSTRACTS OF JAPAN vol. 011, no. 375 (P-644), 8 December 1987 & JP 62 145265 A (FUJI XEROX CO LTD), 29 June 1987, * abstract *	1,11-13, 16,34, 47-49,52	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12 February 1997	Claessen, L

CATEGORY OF CITED DOCUMENTS

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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 11 5368

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	PATENT ABSTRACTS OF JAPAN vol. 010, no. 251 (E-432), 28 August 1986 & JP 61 080922 A (MATSUSHITA ELECTRIC IND CO LTD), 24 April 1986, * abstract *	1,11,14, 34,47,50	
Y	EP 0 453 816 A (TEKTRONIX INC) 30 October 1991 * the whole document *	34,35, 38-41, 54-56, 71-74	
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A	GB 2 280 326 A (MARCONI GEC LTD) 25 January 1995 * figures 1,2 *	34,61, 69,71	TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12 February 1997	Claessen, L

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& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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DEUTSCHES PATENT- UND MARKENAMT

(12) **Offenlegungsschrift**

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(51) Int. Cl.[7]:
H 04 B 10/08
G 01 M 11/00
H 04 B 3/46
H 04 L 12/26

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(22) Anmeldetag: 9. 7. 1998
(43) Offenlegungstag: 20. 1. 2000

DE 198 30 729 A 1

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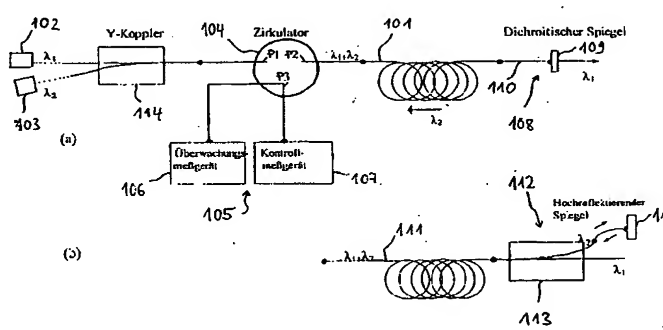
Die folgenden Angaben sind den vom Anmelder eingereichten Unterlagen entnommen

Prüfungsantrag gem. § 44 PatG ist gestellt

(54) Verfahren und Anordnung zur Durchführung von Kontroll- und Überwachungsmessungen an optischen Übertragungsstrecken

(57) Die Erfindung betrifft ein Verfahren und eine Anordnung zur Durchführung von Kontroll- und Überwachungsmessungen an optischen Übertragungsstrecken (101, 111), mit welcher während des regulären Betriebs und ohne Störung desselben Parameter der Übertragungsstrecke (101, 111) gemessen bzw. kontrolliert sowie die Übertragungsstrecke (101, 111) hinsichtlich Abhörversuchen überwacht werden kann. Dazu wird parallel zum Übertragungssignal ein Kontrollsignal mit einer vom Übertragungssignal verschiedenen Wellenlänge in die Übertragungsstrecke (101, 111) eingekoppelt, nach Durchlaufen der Übertragungsstrecke (101, 111) zurückreflektiert und ausgewertet. Zur Reflexion des Kontrollsignals wird eine wellenlängenselektive Reflexionsanordnung (108, 112) verwendet, welche das Übertragungssignal weitgehend ungestört transmittiert, z. B. ein dichroitischer Spiegel (109). Das reflektierte Kontrollsignal wird von einer Erfassungseinrichtung (105) detektiert und hinsichtlich Polarisation, Intensität, Signalform oder anderer Eigenschaften ausgewertet, wodurch auf die Eigenschaften der Übertragungsstrecke geschlossen und/oder ein unerwünschtes Manipulieren am Übertragungssystem detektiert werden kann.



DE 198 30 729 A 1

Beschreibung

Technisches Gebiet

Die Erfindung betrifft ein Verfahren und eine Anordnung zur Durchführung von Kontroll- und Überwachungsmessungen an optischen Übertragungsstrecken gemäß dem Oberbegriff von Anspruch 1 bzw. 8.

Stand der Technik

Eines der wesentlichen Themen der optischen Nachrichtentechnik ist die Sicherheitsüberwachung optischer Übertragungsstrecken. Um Abhörsicherheit und Datenschutz zu garantieren, sind Verfahren bekannt, die einen erheblichen experimentellen Aufwand voraussetzen, z. B. Überwachung der Einwellenfasern mit Hilfe kryptologischer, insbesondere quantenkryptologischer, Methoden oder unter Ausnutzung der Raman- oder Brillouinrückstreuung. Diese äußerst aufwendigen Verfahren dokumentieren das große Interesse an unbeeinflusster, störungsfreier Nachrichtenübertragung.

Weiterhin ist es zur Aufrechterhaltung eines ordnungsgemäßen Telekommunikationsbetriebs über optische Übertragungsstrecken notwendig, die optischen Übertragungsstrecken regelmäßig zu kontrollieren und zu überprüfen. Für spezielle Kabel- oder Glasfasern kann eine Dauerüberwachung erforderlich sein. Insbesondere dafür ist es notwendig, daß die Kontrolle der Betriebsstrecke parallel zum normalen Telekommunikationsbetrieb durchführbar ist, ohne diesen zu stören.

Technische Aufgabe

Der Erfindung liegt daher die Aufgabe zugrunde, ein Verfahren und eine Meßeinrichtung zur Durchführung von Kontroll- und Überwachungsmessungen während des normalen Telekommunikationsbetriebs und ohne Beeinträchtigung desselben zur Verfügung zu stellen. Dabei soll der technische Aufwand so gering wie möglich gehalten werden. Mit dem Verfahren bzw. der Anordnung sollen wesentliche Betriebsparameter der Übertragungsstrecke erfaßbar sein, weiterhin sollen Manipulationen an der Übertragungsstrecke, insbesondere ein Abhören des Datenverkehrs, zuverlässig detektierbar sein.

Offenbarung der Erfindung und ihrer Vorteile

Erfindungsgemäß wird die Aufgabe gelöst durch ein Verfahren und eine Anordnung zur Durchführung von Kontroll- und Überwachungsmessungen an optischen Übertragungsstrecken gemäß der Ansprüche 1 bzw. 8.

Übertragungsstrecken im Sinne der Erfindung sind beispielsweise einzelne optische Fasern oder zu einem Datenkabel zusammengefaßte Faserbündel, aber auch bereits vernetzte Fasern/Kabel oder solche, die durch ein oder mehrere zusätzliche Elemente, wie z. B. Verstärker, unterbrochen sind. Die Übertragungsstrecke hat einen Ein- und einen Ausgang, welche hier die Sende- bzw. Empfangsseite definieren. Sendeseitig werden Daten in Form optischer Signale kodiert (Übertragungssignal), wozu ein Sender mit einer Betriebswellenlänge λ_1 verwendet wird, und in die Übertragungsstrecke eingekoppelt. Der Sender des Übertragungssignals muß sich nicht in unmittelbarer Nähe des sendeseitigen Eingangs der Übertragungsstrecke befinden; es können weitere Übertragungselemente dazwischengeschaltet sein. Empfangsseitig werden die Daten aus der Übertragungsstrecke ausgekoppelt, ausgewertet oder an weitere Übertragungsstrecken weitergeleitet.

Die Betriebswellenlänge ist dabei nicht notwendigerweise genau eine feste Wellenlänge: Übertragungssignale haben aufgrund der zeitlichen Modulation eine gewisse Bandbreite, wobei unter der Betriebswellenlänge die Grundwellenlänge des Übertragungssignals verstanden wird. Weiterhin kann die Übertragungsstrecke im Wellenlängenmultiplexbetrieb (WDM-Betrieb) genutzt werden. Dabei werden mehrere Signale mit unterschiedlichen Grundwellenlängen, die jeweils unterschiedliche, voneinander unabhängige Informationen kodieren, sendeseitig zu einem Übertragungssignal überlagert, übertragen und empfangsseitig wieder getrennt. Die Betriebswellenlänge λ_1 im Sinne der Erfindung ist daher der Wellenlängenbereich, in welchem bei der zu überwachenden Übertragungsstrecke Daten übertragen werden.

Die Erfindung wird im folgenden genauer beschrieben:

Erfindungsgemäß wird ein optisches Kontrollsignal erzeugt mit einer Kontrollwellenlänge λ_2, welche verschieden von der Betriebswellenlänge λ_1 ist. λ_2 ist ebenfalls als Grundwellenlänge des Kontrollsignals zu sehen, welches selbst eine gewisse Bandbreite haben kann. Weiterhin können gleichzeitig auch mehrere Signale mit unterschiedlichen Wellenlängen erzeugt werden, welche nach Art des WDM-Betriebs zu einem Kontrollsignal im Sinne der Erfindung zusammengekoppelt werden.

Die erfindungsgemäße Anordnung weist zur Erzeugung des Kontrollsignals einen Sender auf, welcher gegebenenfalls neben den Sender zur Erzeugung des Übertragungssignals tritt. Das Kontrollsignal wird auf der Sendeseite in die Übertragungsstrecke eingekoppelt. Dabei ist der Einkopplungsmechanismus derart gewählt, daß ein paralleles Einkoppeln des Übertragungssignals möglich ist. Die erfindungsgemäße Anordnung umfaßt dazu einen Koppler, der sendeseitig im Bereich der Übertragungsstrecke angeordnet ist und der die Signale beider Sender in die Übertragungsstrecke einzukoppeln imstande ist. Der Koppler ist beispielsweise ein Multiplexkoppler, wie er auch für den WDM-Betrieb verwendet wird (Y-Koppler): Durch die unterschiedlichen Wellenlängen wird das Übertragungssignal und damit die reguläre Dateneinkopplung nicht gestört.

Das Kontrollsignal wird über die Übertragungsstrecke übertragen, auf der Empfangsseite reflektiert und über die Übertragungsstrecke zurück zur Sendeseite übertragen. Die erfindungsgemäße Anordnung umfaßt dazu eine Reflexionsanordnung, welche auf der Empfangsseite der Übertragungsstrecke angeordnet ist und die Kontrollwellenlänge zu reflektieren imstande ist, wobei das rückreflektierte Kontrollsignal (Reflexionssignal) empfangsseitig wieder in die Übertragungsstrecke eingekoppelt wird.

Die Reflexionsanordnung umfaßt beispielsweise einen dichroitischen Spiegel oder ein dichroitisches Spiegelschichtsystem, welches Strahlung im Bereich der Betriebswellenlänge transmittiert und Strahlung im Bereich der Kontrollwellenlänge reflektiert und am Ausgang der Übertragungsstrecke angeordnet ist. Das Übertragungssignal wird von einem derartigen an die jeweiligen Wellenlängen angepaßten Spiegel mit nur geringer Dämpfung durchgelassen, so daß die reguläre Datenübertragung nicht gestört ist. Gleiches gilt für eine Reflexionsanordnung, die einen in diesem Fall als Demultiplexer verwendeten Multiplexkoppler mit wenigstens zwei wellenlängenabhängigen Ausgängen und einen für die Strahlung im Bereich der Kontrollwellenlänge hochreflektierenden Spiegel umfaßt. Der Ausgang des Multiplexkopplers für Strahlung im Bereich der Betriebswellenlänge ist mit einem Empfänger für Übertragungssignale oder einer weiteren Übertragungsstrecke gekoppelt; am Ausgang für Strahlung im Bereich der Kontrollwellenlänge ist der hochreflektierende Spiegel angeordnet.

Im nächsten Verfahrensschritt wird das rückreflektierte Kontrollsignal (Reflexionssignal) auf der Sendeseite aus der Übertragungsstrecke ausgekoppelt und einer Erfassungseinrichtung zugeführt. Das Einkoppeln der Kontroll- und Übertragungssignale ist im wesentlichen von der Auskopplung des Reflexionssignals unbeeinflußt. Gegebenenfalls ausgekoppeltes Licht der Betriebswellenlänge λ_1 wird unterdrückt.

Das Auskoppeln des Reflexionssignals erfolgt beispielsweise mittels des zur Einkopplung verwendeten (Multiplex-)Kopplers, der für den reflektierten Strahl als Demultiplexer wirkt. In einer anderen vorteilhaften Ausgestaltung umfaßt die erfindungsgemäße Anordnung zur Auskopplung des Reflexionssignals einen Zirkulator, welcher im Bereich des sendeseitigen Endes der Übertragungsstrecke angeordnet ist. Der Zirkulator dient zur sendeseitigen Einkopplung des bereits gemultiplexten Übertragungs- und Kontrollsignals in die Übertragungsstrecke und zur sendeseitigen Auskopplung des Reflexionssignals aus der Übertragungsstrecke. Das Reflexionssignal wird der Erfassungseinrichtung zugeführt.

Die Erfassungseinrichtung gibt schließlich ein Ausgangssignal ab, welches ein Maß für die Intensität und/oder den Polarisationszustand, gegebenenfalls als Funktion der Zeit, und/oder die Signallaufzeit des Reflexionssignals ist und aus welchem Übertragungseigenschaften und/oder Änderungen der Übertragungseigenschaften der Übertragungsstrecke, insbesondere durch Manipulationen an der Übertragungsstrecke, bestimmbar sind.

Die Erfassungseinrichtung umfaßt dazu vorzugsweise einen Detektor, der Strahlung der Kontrollwellenlänge zu detektieren imstande ist und ein intensitätsabhängiges elektrisches Ausgangssignal abgibt. Vorzugsweise umfaßt die Erfassungseinrichtung zudem wenigstens ein polarisationsempfindliches Element, wie Polarisator, Polarisationsstrahlteiler, polarisierender Faserkoppler, insbesondere aber ein Polarimeter, zur Erfassung von wenigstens einer Komponente des Stokesvektors, vorzugsweise des gesamten Polarisationszustands des Reflexionssignals. Die Erfassungseinrichtung kann weiterhin eine Datenverarbeitungsanlage zur weiteren Auswertung der Detektorsignale umfassen.

Das erfindungsgemäße Verfahren ist ohne großen Aufwand zur ständigen oder zeitweisen Kontrolle und Sicherheitsüberwachung installierter Telekommunikationskabel bzw. einzelner Fasern derselben geeignet. Ein Vorteil dieses Verfahrens ist, daß die Kontroll- bzw. Überwachungsmessungen auf der Sendeseite des Übertragungssystems erfolgen, wo im allgemeinen auch das aufwendige Sendesystem installiert ist. Der Platzbedarf, den die erfindungsgemäße Anordnung dazu erfordert, ist außerordentlich gering. Das gilt auch für den technischen Aufwand.

Ein weiterer großer Vorteil der Erfindung liegt darin, daß die Kontroll- bzw. Überwachungsmessungen in keiner Weise den normalen Datentransfer behindern, dieser läuft parallel weiter. Wesentlich ist auch, daß die verwendeten optischen Komponenten kostengünstig sind, wodurch der finanzielle Aufwand, verglichen mit anderen bekannten Verfahren, gering bleibt.

Kurzbeschreibung der Zeichnung, wobei zeigen:

Fig. 1 den prinzipiellen Aufbau einer Anordnung zur Durchführung von Kontroll- und Überwachungsmessungen;

Fig. 2 schematisch eine untersuchte, kontrollierte Übertragungsstrecke, welche mit einer weiteren Übertragungsstrecke gekoppelt ist;

Fig. 3 OTDR-Messungen an einer Übertragungsstrecke;

Fig. 4a, b Fluktuationen der Stokes-Parameter einer ungestörten (a) und einer gestörten (b) Faserstrecke als Funktion der Zeit;

Fig. 4c, d Darstellung des Polarisationszustands des Reflexionssignals auf der Poincarekugel im ungestörten Zustand (c) sowie im Störungsfall (d);

Fig. 5 die Polarisationsmodendispersion einer Faser als Funktion der Wellenlänge im ungestörten bzw. gestörten Zustand.

Wege zur Ausführung der Erfindung

Fig. 1 zeigt das Prinzip eines erfindungsgemäßen Aufbaus für Kontroll- und Überwachungsmessungen an einer optischen Übertragungsstrecke **101** bzw. **111**. Die **Fig.** 1b stellt eine Alternative zur Realisierung der Erfindung auf der Empfangsseite gemäß **Fig.** 1a dar; der linke (sendeseitige) Teil der erfindungsgemäßen Anordnung aus **Fig.** 1b entspricht dem aus **Fig.** 1a und ist nicht dargestellt.

Neben dem optischen Übertragungssignal mit der Betriebswellenlänge λ_1, das von einem Sender **102** erzeugt wird, wird ein Kontrollsignal mit der Kontrollwellenlänge λ_2 von einem zweiten Sender **103** erzeugt und in einen Koppler **114** eingekoppelt. Der Koppler **114** ist ein breitbandiger Y-Koppler, z. B. ein Multiplexkoppler. Ausgangsseitig ist der Koppler **114** mit einem Zirkulator **104** über dessen Port P1 verbunden. Der Port P2 des Zirkulators **104** wird mit dem Eingang der zu testenden Übertragungsstrecke **104** gekoppelt, z. B. zusammengesteckt oder gespleißt. Mit dem dritten Port P3 des Zirkulators **104** ist die Erfassungseinrichtung **105** verbunden, welche hier zur Durchführung von Kontroll- und Überwachungsmessungen aus einem Überwachungsmeßgerät **106** und einem Kontrollmeßgerät **107** besteht.

Der Zirkulator hat die Eigenschaft, am Port P1 eingekoppeltes Licht weitgehend verlustfrei zum Port P2 durchzulassen, die Übertragung zum Port P3 jedoch extrem zu dämpfen. Am Port P2 eingekoppeltes Licht wird dagegen zum Port P3 geleitet, wobei die Übertragung von P2 nach P1 extrem gedämpft ist. Damit wirkt der Zirkulator **104** als optisches Ventil, welches Strahlung je nach Ausbreitungsrichtung in unterschiedliche Ausgangskanäle leitet.

Am Ausgang der Übertragungsstrecke **101** bzw. **111** ist eine Reflexionsanordnung **108** bzw. **112** angebracht, die zur Reflexion des Kontrollsignals mit der Kontrollwellenlänge λ_2, dient. Die Reflexionsanordnung **108** besteht in **Fig.** 1a aus einem kurzen Glasfaserstück **110**, an dessen hinterem Ende ein dichroitischer Spiegel **109** angebracht ist. Das vordere Ende des Glasfaserstücks **110** ist beispielsweise mit einem optischen Stecker versehen, mit welchem es mit dem empfangsseitigen Ausgang der Übertragungsstrecke zusammengesteckt wird. Der dichroitische Spiegel **109** reflektiert im Bereich der Kontrollwellenlänge λ_2, vorzugsweise mit einem Reflexionsgrad von mehr als 95%, idealerweise mehr als 99%, und transmittiert im Bereich der Betriebswellenlänge λ_1, vorzugsweise mit einem Transmissionsgrad von wenigstens 95%.

Der dichroitische Spiegel **109** kann in einen speziellen Stecker integriert sein, z. B. indem auf die Stirnfläche des Steckers eines dichroitisches Spiegelschichtsystem aufgeklebt ist. Das dichroitische Spiegelschichtsystem ist so ausgelegt, daß die Betriebswellenlänge λ_1 mit hohem Transmissionsgrad den Spiegel passieren kann. Das Übertragungssignal wird dann folgendem Kabelabschnitt zugeführt, siehe z. B. **Fig.** 2, oder von einem Empfänger empfangen und ausgewertet. Die Kontrollwellenlänge λ_2 hingegen wird mit hohem Wirkungsgrad reflektiert. Mit Hilfe der nur geringfügig gedämpften Betriebswellenlänge wird der Betriebsverkehr aufrechterhalten, die reflektierte Kontrollwellenlänge hingegen dient sendeseitig zur kontinuierlichen Überwachung der Übertragungsstrecke **101** und für Kontrollmessungen.

In **Fig.** 1b ist eine alternative Realisierung einer Reflexionsanordnung **112** dargestellt. Die Reflexionsanordnung **112** umfaßt in diesem Fall einen Koppler **113**, welcher als Demultiplexer fungiert. Das Übertragungssignal mit der Betriebswellenlänge λ_1 wird über einen Arm des Kopplers **113** dem nächsten Kabelabschnitt oder einem Empfänger zugeführt. Das Kontrollsignal hingegen wird im zweiten Arm des Kopplers geführt, an dessen Ausgang ein – wenigstens im Bereich der Kontrollwellenlänge – hochreflektierender Spiegel **115** angeordnet ist. Der Spiegel **115** ist vorzugsweise als hochreflektierender Faserstecker ausgeführt, welcher an den entsprechenden Ausgang des Demultiplexers **113** angekoppelt wird. Das Kontrollsignal wird an diesem Spiegel **115** derart reflektiert, daß es empfangsseitig wieder in die Übertragungsstrecke **111** eingekoppelt wird, auf Port P2 des Zirkulators **104** fällt und schließlich zur Erfassungseinrichtung **105** übertragen wird.

Die reflektierte Strahlungsleistung wird am Port P3 des Zirkulators **104** ausgekoppelt und als Reflexionssignal der Erfassungseinrichtung **105** bzw. einem der Meßgeräte **106**, **107** zugeführt. Anhand des Reflexionssignals können Kontroll- und Überwachungsmessungen aller Art durchgeführt werdend ohne daß der eigentliche Telekommunikationsbetrieb gestört oder beeinflußt wird.

Der Koppler **114** ist vorzugsweise breitbandig und für Wellenlängen im Bereich von 1300 bis 1650 nm geeignet. Die Einfügeverluste sind vorzugsweise geringer als 0,2 dB. Der Zirkulator ist, falls er universell verwendet werden soll, möglichst breitbandig. Ansonsten kann ein Zirkulator für jedes der beiden optischen Fenster verwendet werden. Die Einfügeverluste sind im ersten Fall vorzugsweise geringer als 0,8 dB, im zweiten Fall geringer als 0,6 dB. Die Isolationswerte für eine Übertragung von Port P2 nach P1 und Port P3 nach P2 sind im ersten Fall vorzugsweise größer als 35 dB, im zweiten Fall vorzugsweise größer als 45 dB. Die Directivity beträgt vorzugsweise wenigstens 60 dB, entsprechend einer sehr hohen Isolation auf dem direkten Weg von Port P1 nach P3.

Die Betriebswellenlänge λ_1 liegt je nach Betriebssystem im zweiten oder dritten optischen Fenster, also um 1300 bzw. 1550 nm. Für die Kontrollwellenlänge λ_2 gibt es keine prinzipiellen Einschränkungen. Vorzugsweise ist sie größer als die Betriebswellenlänge, liegt beispielsweise oberhalb von 1600 nm. Bei den herkömmlichen optischen Standardfasern mit einer Grenzwellenlänge von etwa 1300 nm läuft bei einer solch großen Wellenlänge ein beträchtlicher Teil des Kontrollsignals im Fasermantel. Dadurch wird die Faser sehr empfindlich gegen Biegungen der Faser bzw. des Kabels, wodurch die Empfindlichkeit des Meßverfahrens erhöht ist. Um hohe Faserdämpfung zu vermeiden, sollte die Kontrollwellenlänge allerdings nicht zu groß gewählt werden, sondern vorzugsweise noch im dritten optischen Fenster liegen.

Die Sender **102** und **103** für das Übertragungssignal bzw. das Kontrollsignal sind Strahlungsquellen, die optische Signale mit hoher Strahlqualität erzeugen. Vorzugsweise finden Infrarotlaser Anwendung, z. B. Farbstofflaser oder Laserdioden. Das Kontrollsignal wird im Puls- oder im Dauerstrichbetrieb erzeugt. Gegebenenfalls kann dem Kontrollsignal auch zusätzliche Information aufmoduliert sein, was z. B. für Bitfehlerratenmessungen vorteilhaft ist. Das Kontrollsignal kann zur Durchführung von wellenlängenabhängigen Messungen, z. B. Messung der spektralen Polarisationsmodendispersion (siehe **Fig.** 4), auch hinsichtlich der Kontrollwellenlänge durchgestimmt werden. Dazu werden beispielsweise thermisch durchstimmbare DFB-Halbleiter oder durchstimmbare External-Cavity-Laser verwendet.

Bei der Verbindung zwischen Port P2 des Zirkulators **104** und der Übertragungsstrecke **101** sowie bei sämtlichen anderen optischen Kopplungen innerhalb des Ausbreitungswegs des Übertragungssignals sollten Reflexionen vermieden werden. Dazu werden die optischen Verbindungen vorzugsweise als Spleißverbindung ausgeführt. Falls eine Steckverbindung nötig ist, sollte innerhalb des Steckers Immersionsöl verwendet werden. Vorzugsweise beträgt die Reflexion an den Kopplungsstellen weniger als 1%.

Fig. 2 zeigt schematisch, wie eine untersuchte, kontrollierte Übertragungsstrecke **201**, die einen ersten Kabelabschnitt bildet, über einen dichroitischen Spiegel **203** mit einer weiteren Übertragungsstrecke **204** verbunden ist, welche einen zweiten Kabelabschnitt bildet. Der dichroitische Spiegel **203** ist dabei wie in **Fig.** 1a Hauptbestandteil der Reflexionsanordnung **202**, mit welcher die Kontrollwellenlänge λ_2 reflektiert, das eigentliche Übertragungssignal mit der Wellenlänge λ_1 jedoch weitgehend unbeeinflußt zum zweiten Kabelabschnitt übertragen wird. Anstelle der zweiten Übertragungsstrecke **204** kann sich hinter dem dichroitischen Spiegel **203** jedes beliebige andere Element anschließen, welches empfangsseitig in optischen Übertragungssystemen Verwendung findet.

Mit dem optischen Aufbau gemäß der **Fig.** 1a und 1b sind Kontroll- und Überwachungsmessungen auch während des regulären Telekommunikationsbetriebs weitgehend störungsfrei durchführbar. Unter Kontrollmessungen werden dabei solche Messungen verstanden, welche der Kontrolle der Übertragungseigenschaften der Übertragungsstrecke dienen. Dazu gehört die Messung bzw. die Überprüfung bestimmter Faserparameter, z. B. die chromatische Dispersion mit ihren essentiellen Parametern, wie die Nulldispersionswellenlänge λ_0, der Anstieg der Dispersionskurve bei λ_0 oder die Dispersionswerte im zweiten und dritten optischen Fenster, die spektrale Streckendämpfung, die Polarisationsmodispersion oder auch Bitfehlerratenmessungen.

Überwachungsmessungen sind demgegenüber Messungen, die für die Sicherheit des Übertragungssystems relevant sind. Mit Überwachungsmessungen lassen sich beispielsweise Manipulationen an der Übertragungsstrecke detektieren. Somit läßt sich beispielsweise ein "Abhören" des Datenverkehrs durch Abzweigen auch nur geringster Leistungen anzeigen.

Beide Arten von Messungen unterliegen keinen prinzipiellen Einschränkungen, zumal der Vorzug des Verfahrens ausgenutzt werden kann, daß alle Sende- und Meßeinrichtungen auf der Sendeseite untergebracht sind und somit sämtliche Daten unmittelbar zur Auswertung zur Verfügung stehen. Empfangsseitig muß lediglich für die Reflexion des Kontrollsignals gesorgt werden.

So sind als Kontrollmessungen beispielsweise kontinuierliche Lebensdauermessungen problemlos und störungsfrei durchführbar. Aus Vergleich von Reflexions- und ursprünglich erzeugtem Kontrollsignal, z. B. hinsichtlich Polarisation, Laufzeit, Signalform, Amplitude bzw. Intensität, kann auf eine Vielzahl von Parametern der Übertragungsstrecke geschlossen werden. Diese Messungen sind durch Wahl einer geeigneten Erfassungseinrichtung, die die jeweils interessierenden Größen zu detektieren imstande ist, mit einem Aufbau nach **Fig.** 1 durchführbar.

Weiterhin sind als Kontrollmessungen auch direkte Faserlängenmessungen der Fasern eines Kabels möglich. Es ist bekannt, daß die optische Faserlänge erheblich größer ist als die entsprechende Kabellänge, außerdem sind auch die Längen der einzelnen Fasern eines Kabels unterschiedlich lang. Diese Messungen gestalten sich sehr einfach und werden beispielsweise mit einem erfindungsgemäßen Aufbau nach **Fig.** 3 durchgeführt.

Fig. 3 zeigt dazu ein Übertragungssystem, bestehend aus

einer Übertragungsstrecke **301**, über welche ein Übertragungssignal mit der Wellenlänge λ_1 übertragen wird. Das Übertragungssignal kommt von einem Sender, gegebenenfalls über einen anderen Teil des Übertragungssystems (andere Faserstrecke). Erfindungsgemäß wird über die Übertragungsstrecke **301** ein Kontrollsignal der Wellenlänge λ_2 übertragen zur Messung von Eigenschaften der Übertragungsstrecke **301**. Das Kontrollsignal wird von einem Optical Time Domain Reflectometer (OTDR) erzeugt, welcher mit einem Sender **302** der Kontrollwellenlänge λ_2 ausgestattet ist.

Das Kontrollsignal wird zusammen mit dem Übertragungssignal mittels eines Kopplers **306** in die Übertragungsstrecke **301** eingekoppelt. Es wird nach Durchlaufen der Übertragungsstrecke **301** an einem Spiegel **305**, der am Ausgang der Übertragungsstrecke **301** angeordnet ist, reflektiert, wobei das Übertragungssignal transmittiert wird. Als Reflexionsanordnung kommt auch wieder die in **Fig.** 1a dargestellte Alternative in Frage.

Der Zirkulator aus dem Aufbau nach **Fig.** 1 ist bei der optischen Anordnung nach **Fig.** 3 nicht notwendig da der OTDR als Empfänger **303** das rückgestreute Licht mit λ_2 auswertet. Ein einfacher Bandpaßfilter **307** vor dem Ein- bzw. Ausgang des OTDR unterdrückt die rückgestreute Strahlung mit λ_1. Das Aufbauprinzip ist in **Fig.** 3 dargestellt.

Der OTDR erzeugt ein kurzes Kontrollsignal mit λ_2 und wertet das rückreflektierte Signal aus. Aus der zeitlichen Differenz zwischen Erzeugung des Kontrollsignals und Empfang des Reflexionssignals wird die optische Länge der Übertragungsstrecke ermittelt. Wenn man die OTDR gemessene rückgestreute Leistung logarithmisch über den optischen Weg in der Testfaser aufträgt, erhält man eine abfallende Gerade (negative Steigung). Das Faserende wird durch den auftretenden Fresnelimpuls definiert. Stufen in der abfallenden Geraden zeigen Spleiße an, die Stufenhöhe ist ein Maß für die Spleißdämpfung. Faserbrüche oder -fehlstellen erzeugen Fresnelreflexionen, die so genau lokalisiert werden können. Der Zusammenhang zwischen der gemessenen Gruppenlaufzeit t_g und der Faserlänge L ist $L = t_g c/n_g$, d. h. bei genauer Kenntnis n_g kann L, bzw. jeder Ortsabstand in der Faser exakt bestimmt werden. Durch spezielle Meßanordnungen kann mit dem OTDR auch die örtlich verteilte PMD gemessen werden.

Neben den Kontrollmessungen sind auch sicherheitsrelevante Überwachungsmessungen mit der Erfindung auf einfache Weise ohne großen technischen Aufwand durchführbar. Für Überwachungsmessungen wird beispielsweise der Aufbau nach **Fig.** 1 verwendet.

Bei einem ersten Verfahren wird die relative Dämpfung des Kontrollsignals sendeseitig unter Zuhilfenahme der Erfassungseinrichtung **105** bestimmt. Dazu wird vorgeschlagen, nach der Meßmethode nach Heitmann zu verfahren (W. Heitmann, Precision Single-Mode Fiber Spectral Attenuation Measurements, J. Opt. Comm., Vol 8 (1987), No. 1 p. 2; W. Heitmann Attenuation Analysis of Silica-Based Single-Mode Fibers, J. Opt. Comm., Vol 11 (1990), No. 4 p. 122).

Da aber nicht die absoluten Dämpfungswerte interessieren, sondern nur kleine Änderungen der Dämpfung, ist es nicht notwendig, die sogenannte Rückschneidemethode zu praktizieren. Bei der Rückschneidemethode wird nach einer Transmissionsmessung die Faser einige Meter hinter der Einkoppelstelle abgeschnitten und die Transmissionsleistung erneut gemessen. Die Dämpfung kann mit hoher Genauigkeit gemessen werden, wenn die Einkoppelbedingungen des Kontrollsignals konstant gehalten werden (max. 0,001 dB). Jeder Eingriff, der an der entsprechenden Übertragungsstrecke bzw. Faser derselben vorgenommen wird, wird durch die Messung der Dämpfung detektiert. Ein Anzapfen einer Leitung zu Abhörzwecken bedingt ein Auskoppeln von Lichtleistung über den Fasermantel. Durch Messung der Dämpfung lassen sich selbst die dadurch bedingte Abzweigung sehr kleiner Lichtleistungen von minimal 0,002 dB erfassen.

Es ist nicht notwendig, in diesem Fall die Dämpfungsmessung spektral durchzuführen; eine Messung für die Kontrollwellenlänge ist ausreichend. Die Kontrollwellenlänge sollte möglichst groß gewählt werden, denn bei großen Wellenlängen im Monomodebereich wird ein erheblicher Teil der Lichtleistung im Fasermantel geführt, wodurch Dämpfungsänderungen durch Hantieren an der Faser größer und damit zuverlässiger detektierbar werden. Die Kontrollwellenlänge sollte allerdings nur so groß gewählt werden, daß die Dämpfungsverluste über die gesamte Übertragungsstrecke im Normalfall, d. h. ohne Eingriff von außen, noch vertretbar sind.

Eine weitere Methode zur Durchführung einer Überwachungsmessung mittels der Erfindung basiert auf der Tatsache, daß der Polarisationszustand (SOP) eines über eine Faserstrecke übertragenen Signals empfindlich von Biegungen und Erschütterungen der Faser abhängt: Durch Manipulieren an der Faser wird lokal deren Doppelbrechung geändert, wodurch sich auch der Polarisationszustand des Signals schlagartig ändert. Diese Methode ist weitaus empfindlicher als die Dämpfungsmethode und macht ein unentdecktes Hantieren am Kabel weitgehend unmöglich.

Diese Änderung des SOP kann beispielsweise mit Hilfe eines Polarimeters leicht nachgewiesen werden, indem der Stokesvektor auf der Poincarekugel dargestellt wird. Der prinzipielle Aufbau zur Streckenüberwachung durch Beobachtung des Polarisationszustands mit Hilfe eines polarisationssensiblen Überwachungsgeräts **106** ist in **Fig.** 1a, b skizziert. In **Fig.** 4a ist der zeitliche Verlauf der drei Komponenten S_1, S_2, S_3 des Stokesvektors im ungestörten Zustand dargestellt, die Meßzeit ist 8000 s. In **Fig.** 4b ist der zeitliche Verlauf der Stokeskomponenten innerhalb von nur 3 s im Störungsfalle gezeigt. Das Bild dokumentiert eindrucksvoll den dramatischen Einfluß von Störungen auf den zeitlichen Verlauf des SOP.

Das wird ebenso eindrucksvoll bestätigt durch die korrespondierende Darstellung auf der Poincarekugel gemäß der **Fig.** 4c und 4d.

Fig. 4c zeigt die langsame Drift des SOP auf der Kugeloberfläche im ungestörten Zustand (Meßzeit wiederum 8000 s), während in **Fig.** 4d der Störungsfall gezeigt wird (Meßzeit 3 s), in dem der Stokesvektor über den gesamten Bereich der Kugeloberfläche erheblich fluktuiert. Man beachte den großen Unterschied der Beobachtungszeit, zum einen 8000 s, zum anderen nur 3 s.

Zum Nachweis der Änderung des SOP gibt es mehrere Möglichkeiten.

a) Die aufwendigste Methode wurde bereits erwähnt. Mit Hilfe eines Polarimeters wird der vollständige Polarisationszustand erfaßt. Im ungestörten Betrieb ändert sich der SOP, z. B. als Folge thermischer Einflüsse, sehr langsam und stetig (siehe **Fig.** 4a und 4c). Der Punkt auf der Oberfläche der Poincarekugel, der den jeweiligen Polarisationszustand repräsentiert, driftet langsam in eine beliebige Richtung. Wird hingegen die Faser berührt, erfolgt eine sprunghafte Veränderung der Position des Punktes, beim Hantieren an der Faser ändert sich die Bewegung des SOP-Punktes in Richtung und Betrag nahezu in statistischer Weise (siehe **Fig.** 4b und 4d). Dieser Prozeß ist so auffällig, daß er sofort ins Auge fällt und detektierbar ist.

Die sprunghafte Änderung des SOP aufgrund einer äußeren Störung äußert sich auch in einer erhöhten Polarisationsmodendispersion (PMD) und ist durch Messung der PMD detektierbar. **Fig. 5** zeigt dazu den spektralen Verlauf der Polarisationsmodendispersion in ps zwischen 1540 und 1560 nm ohne Störung (oben) und mit Störung (unten), die durch Berührung der Testfaser, in diesem Fall einer 23.13 km lange Glasfaser auf einer Spule, verursacht wurde. Durch die Störungen bei 1545, 1555 und 1559 nm erhöhen sich die PMD-Werte um einen Faktor bis zu 25 in diesem Fall. **Fig. 5** dokumentiert den starken Einfluß von Störungen sogar auf die PMD. Als Meßverfahren im Sinne der hier vorgestellten Arbeit kommt diese Methode nur in Betracht, wenn die Kontrollwellenlänge mit Hilfe eines durchstimmbaren Lasers variiert und das zeitliche Auseinanderlaufen des Signals als Funktion der Wellenlänge aufgezeichnet wird. Dies ist allerdings, bedingt durch das notwendige Durchstimmen des Lasers, für Routinemessungen in der Regel zu zeitaufwendig.

b) Zur Feststellung der Veränderung des SOP ist seine vollständige Bestimmung durch die drei normierten Stokesparameter mit Hilfe eines Polarimeters nicht unbedingt erforderlich. Im allgemeinen ist zur Detektierung der Veränderung des SOP die Erfassung von einer oder zwei Komponenten des Stokesvektors ausreichend (s. **Fig.** 4a, b). Deshalb wird für eine weniger aufwendige Variante das Polarimeter durch ein polarisationsempfindliches Element (Polarisator, Polarisationsstrahlteiler, polarisationsabhängiger Faserkoppler usw.) ersetzt. Die diese Komponenten passierenden Strahlungsanteile werden detektiert und die entsprechenden Detektorspannungen ausgewertet. Solange die Faser ungestört im Kabel ruht, ändert sich die Detektorspannung nur sehr langsam und stetig, bei Störungen, Manipulationen hingegen erfolgt eine plötzliche und starke Änderung. Für die automatische Überwachung ist daher ein Diskriminator vorteilhaft, um diese sehr unterschiedlichen Effekte zu unterscheiden. Dies kann beispielsweise ein Frequenzfilter sein, der niedrige Frequenzen (beispielsweise < 0.1 Hz) eliminiert. Zur Erhöhung der Auswertesicherheit wird neben dem Frequenzfilter ein Schwellenwertschalter eingesetzt, der verhindert, daß kleine, rauschartige Spannungswerte ausgewertet werden, die auch sehr hohe Frequenzkomponenten enthalten. Nur Amplituden oberhalb des Schwellenwertes, der variabel einstellbar sein sollte, werden aufgezeichnet.

Bezugszeichenliste

101, 111, 201, 301 Übertragungsstrecke (Teststrecke)
102 Sender (Übertragungssignal)
103, 302 Sender (Kontrollsignal)
104 Zirkulator
105, 303 Erfassungseinrichtung
106, 107 Überwachungs- bzw. Kontrollmeßgerät
108, 112, 202, 304 Reflexionsanordnung
109, 203 dichroitischer Spiegel
110 Kabelstück
113, 114, 306 Koppler
115, 305 Spiegel
204 weitere, nicht zu testende Übertragungsstrecke
307 Filter

Patentansprüche

1. Verfahren zur Durchführung von Kontroll- und Überwachungsmessungen an optischen Übertragungsstrecken (**101, 111, 201, 301**), wie einzelnen optischen Fasern oder Faserbündeln, mit einer Sende- und einer Empfangsseite, wobei über die Übertragungsstrecke Daten in Form optischer Signale (Übertragungssignal) mit einer Betriebswellenlänge λ_1 übertragen werden, **dadurch gekennzeichnet**, daß
   a) ein optisches Kontrollsignal mit einer Kontrollwellenlänge λ_2, welche verschieden von der Betriebswellenlänge λ_1 ist, auf der Sendeseite in die Übertragungsstrecke eingekoppelt wird, wobei der Einkopplungsmechanismus derart gewählt ist, daß ein paralleles Einkoppeln des Übertragungssignals möglich ist,
   b) das Kontrollsignal auf der Empfangsseite reflektiert und über die Übertragungsstrecke zurück zur Sendeseite übertragen wird,
   c) das rückreflektierte Kontrollsignal (Reflexionssignal) auf der Sendeseite aus der Übertragungsstrecke ausgekoppelt und einer Erfassungseinrichtung (**105, 303**) zugeführt wird, wobei das Einkoppeln der Kontroll- und Übertragungssignale im wesentlichen von der Auskopplung des Reflexionssignals unbeeinflußt ist und gegebenenfalls ausgekoppeltes Licht der Betriebswellenlänge λ_1 unterdrückt wird,
   d) die Erfassungseinrichtung ein Ausgangssignal abgibt, welches ein Maß für die Intensität und/oder den Polarisationszustand, gegebenenfalls als Funktion der Zeit, und/oder die Signallaufzeit des Reflexionssignals ist und aus welchem Übertragungseigenschaften der Übertragungsstrecke und/oder Änderungen der Übertragungseigenschaften, insbesondere durch Manipulationen an der Übertragungsstrecke, bestimmbar sind.
2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß es während des normalen Übertragungsbetriebs durchgeführt wird, wobei das Kontrollsignal parallel zum Übertragungssignal in die Übertragungsstrecke eingekoppelt wird.
3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß das Kontrollsignal auf der Empfangsseite wellenlängenspezifisch weitestgehend reflektiert wird, vorzugsweise mit einem Reflexionsgrad von R > 95%, und das Übertragungssignal weitestgehend transmittiert wird, vorzugsweise mit einem Transmissionsgrad von T > 95%.
4. Verfahren nach einem der vorangegangenen Ansprüche, dadurch gekennzeichnet, daß die Kontrollwellenlänge derart gewählt ist, daß sie wenigstens teilweise über den Mantel der optischen Faser übertragen wird, jedoch bei der Übertragung nicht wesentlich gedämpft wird.
5. Verfahren nach einem der vorangegangenen Ansprüche, dadurch gekennzeichnet,
daß durch Auswertung des Reflexionssignals die chromatische Dispersion der Faser, insbesondere die Nulldispersionswellenlänge λ_0, der Anstieg der Dispersionskurve bei λ_0 und/oder die Dispersionswerte im zweiten oder dritten optischen Fenster, und/oder die spektrale Streckendämpfung und/oder die Polarisationsmodendispersion bestimmt wird.
6. Verfahren nach einem der vorangegangenen Ansprüche, dadurch gekennzeichnet, daß das zeitabhängige Ausgangssignal der Erfassungseinrichtung zur

Unterdrückung statistischer Fluktuationen gefiltert wird, vorzugsweise die Bandbreite des Ausgangssignals auf Frequenzen im Bereich zwischen etwa 0,1 und 100 Hz begrenzt wird.

7. Anordnung zur Durchführung von Kontroll- und Überwachungsmessungen an optischen Übertragungsstrecken (**101, 111, 201, 301**), wie einzelnen optischen Fasern oder Faserbündeln wobei die Übertragungsstrecke eine Sende- und eine Empfangsseite aufweist und an der Sendeseite ein optisches Übertragungssignal mit einer Betriebswellenlänge λ_1 in die Übertragungsstrecke eingekoppelt und über diese übertragen wird, gekennzeichnet durch:

a) einen Sender (**103, 302**) zur Erzeugung eines optischen Kontrollsignals mit einer von der Betriebswellenlänge λ_1 verschiedenen Kontrollwellenlänge λ_2, der auf der Sendeseite der Übertragungsstrecke angeordnet ist;

b) einen Koppler (**114, 306**), der Übertragungs- und Kontrollsignal sendeseitig in die Übertragungsstrecke einzukoppeln imstande ist;

c) eine Reflexionsanordnung (**108, 112, 202, 304**), welche auf der Empfangsseite der Übertragungsstrecke angeordnet ist und die Kontrollwellenlänge zu reflektieren imstande ist, wobei das rückreflektierte Kontrollsignal (Reflexionssignal) empfangsseitig wieder in die Übertragungsstrecke eingekoppelt wird;

d) eine Erfassungseinrichtung (**105, 303**) zur Erfassung von Parametern des rückreflektierten Kontrollsignals (Reflexionssignal), die auf der Sendeseite der Übertragungsstrecke angeordnet und ein Ausgangssignal abzugeben imstande ist, welches ein Maß für die Intensität und/oder den Polarisationszustand, gegebenenfalls als Funktion der Zeit, und/oder die Signallaufzeit des Reflexionssignals ist.

8. Anordnung nach Anspruch 8, dadurch gekennzeichnet, daß der Koppler ein breitbandiger Multiplexkoppler (Y-Koppler) ist.

9. Anordnung nach Anspruch 8 oder 9, dadurch gekennzeichnet, daß die Reflexionsanordnung einen dichroitischen Spiegel (**109, 203**) umfaßt, welcher Strahlung im Bereich der Betriebswellenlänge λ_1 transmittiert und Strahlung im Bereich der Kontrollwellenlänge λ_2 reflektiert.

10. Anordnung nach Anspruch 10, dadurch gekennzeichnet, daß die Reflexionsanordnung einen Multiplexkoppler (**113**) (Demultiplexer) mit wenigstens zwei wellenlängenabhängigen Ausgängen umfaßt, wobei der Ausgang für Strahlung im Bereich der Betriebswellenlänge mit einem Empfänger für Übertragungssignale oder einer weiteren Übertragungsstrecke gekoppelt und am Ausgang für Strahlung im Bereich der Kontrollwellenlänge ein die Kontrollwellenlänge λ_2 hochreflektierender Spiegel (**115**) angeordnet ist.

11. Anordnung nach einem der Ansprüche 8 bis 11, dadurch gekennzeichnet, daß sie einen Zirkulator (**104**) umfaßt, welcher im Bereich des sendeseitigen Endes der Übertragungsstrecke angeordnet ist, zur sendeseitigen Einkopplung des Übertragungs- und Kontrollsignals in die Übertragungsstrecke und zur sendeseitigen Auskopplung des Reflexionssignals aus der Übertragungsstrecke.

12. Anordnung nach einem der Ansprüche 8 bis 11, dadurch gekennzeichnet, daß der zweite Sender (**302**) einen Optical Time Domain Reflectometer (OTDR) umfaßt, welcher mit einer Signalquelle, insbesondere einem Laser, zur Erzeugung des Kontrollsignals und einem Empfänger zum Empfang des Reflexionssignals ausgestattet ist, und der ODTR somit auch als Erfassungseinrichtung (**303**) fungiert.

13. Anordnung nach Anspruch 13, dadurch gekennzeichnet, daß vor dem Ein- bzw. Ausgang des ODTR ein Filter (**307**) angeordnet ist, welches die Betriebswellenlänge unterdrückt und die Kontrollwellenlänge transmittiert.

14. Anordnung nach einem der Ansprüche 8 bis 14, dadurch gekennzeichnet, daß die Erfassungseinrichtung (**105, 303**) einen Detektor umfaßt, der Strahlung im Bereich der Kontrollwellenlänge zu detektieren und ein elektrisches Ausgangssignal abzugeben imstande ist, welches ein Maß für die Intensität der auf den Detektor fallenden Strahlung ist.

15. Anordnung nach Anspruch 15, dadurch gekennzeichnet, daß die Erfassungseinrichtung ein polarisationsempfindliches Element, wie Polarisator, Polarisationsstrahlteiler, polarisierender Faserkoppler, umfaßt zur Erfassung von wenigstens einer Komponente des Stokesvektors des Reflexionssignals.

16. Anordnung nach Anspruch 16, dadurch gekennzeichnet, daß die Erfassungseinrichtung ein den vollständigen Polarisationszustand (vollständigen Stokesvektor) des Reflexionssignals erfassendes Polarimeter umfaßt.

Hierzu 5 Seite(n) Zeichnungen

Nummer: DE 198 30 729 A1
Int. Cl.[7]: H 04 B 10/08
Offenlegungstag: 20. Januar 2000

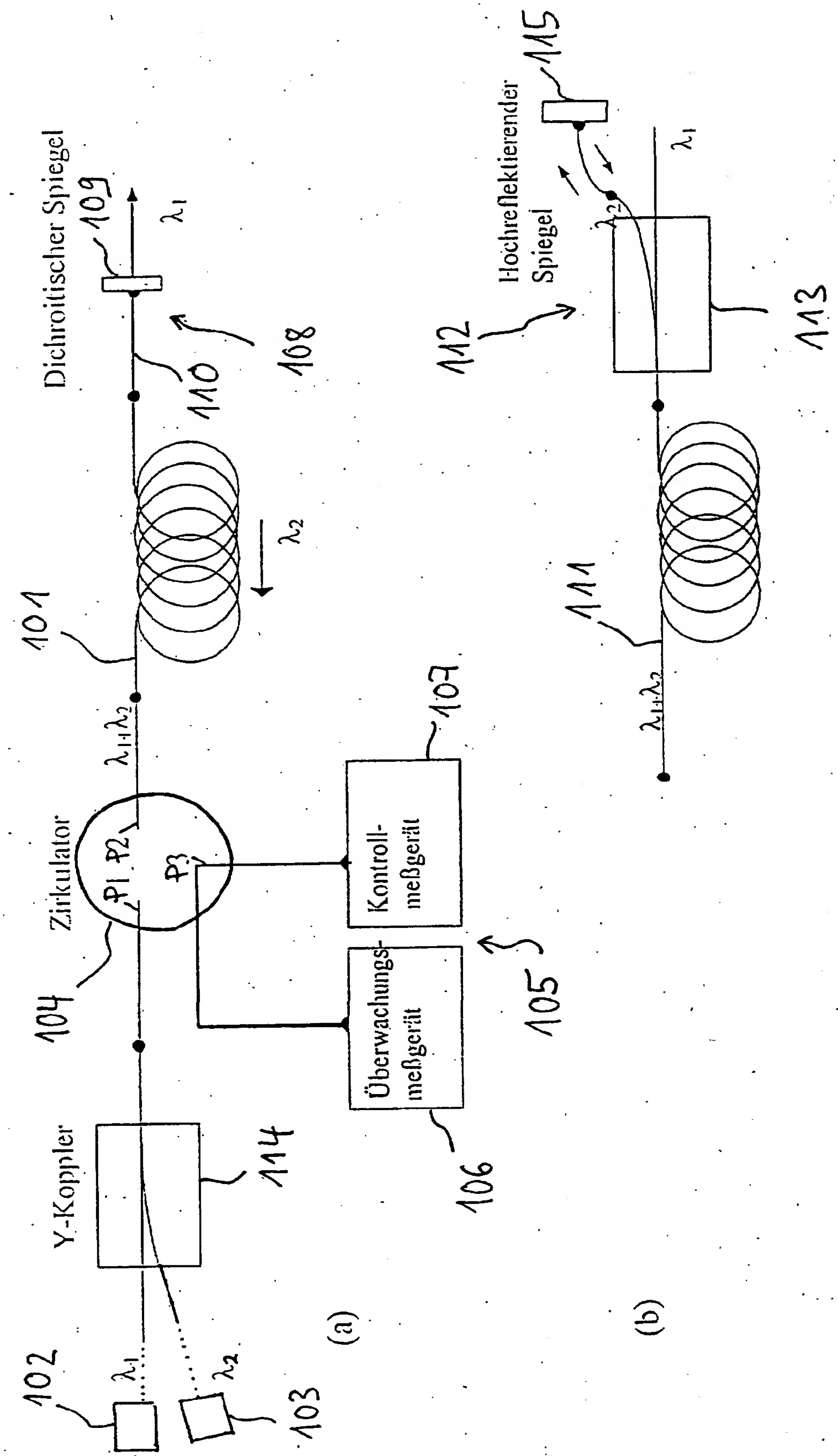


Fig. 1 Prinzipaufbau für Kontroll- und Überwachungsmessungen

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Offenlegungstag: 20. Januar 2000

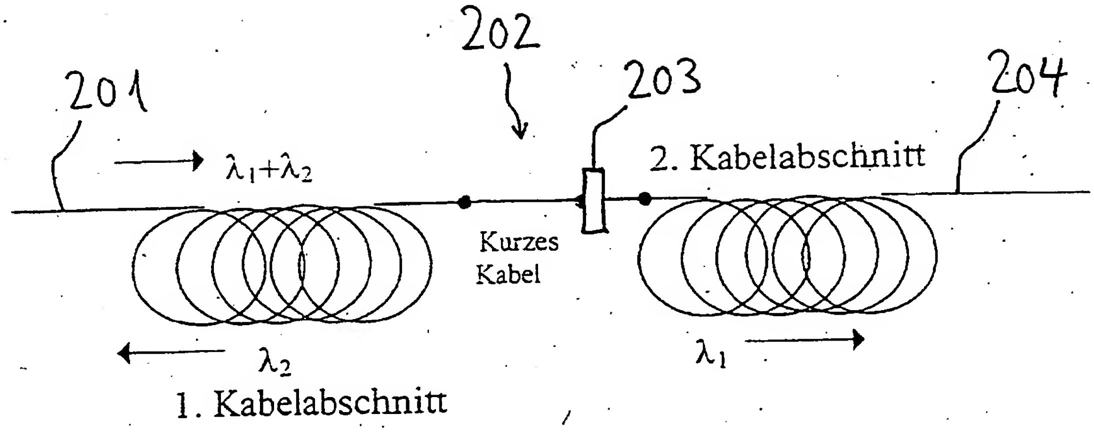


Fig. 2 Untersuchte, kontrollierte Testfaser (1. Kabelabschnitt) verbunden über den dichroitischen Spiegel mit dem folgenden Kabelabschnitt

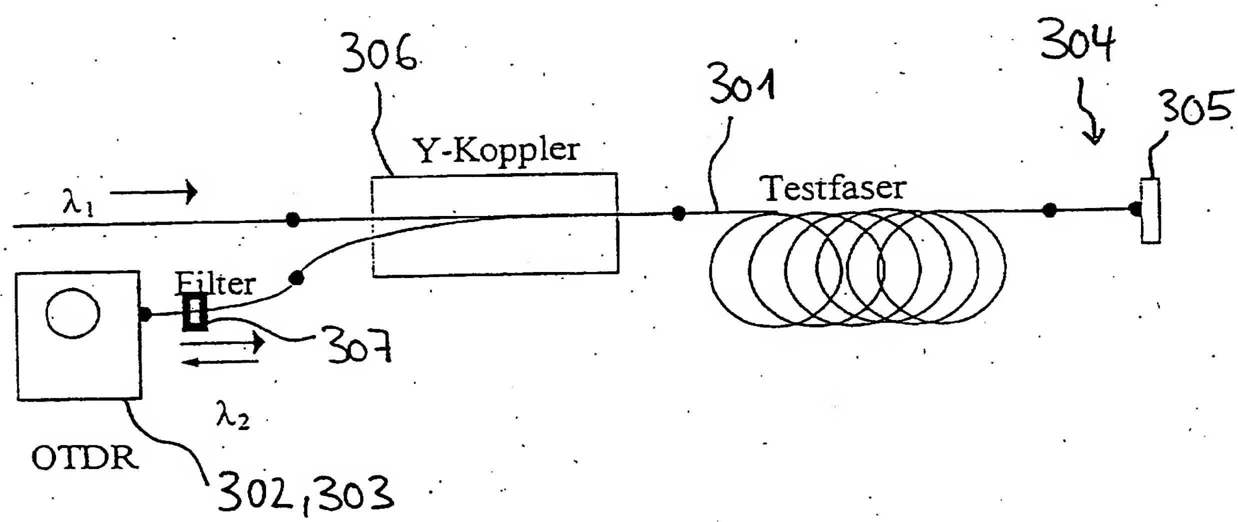
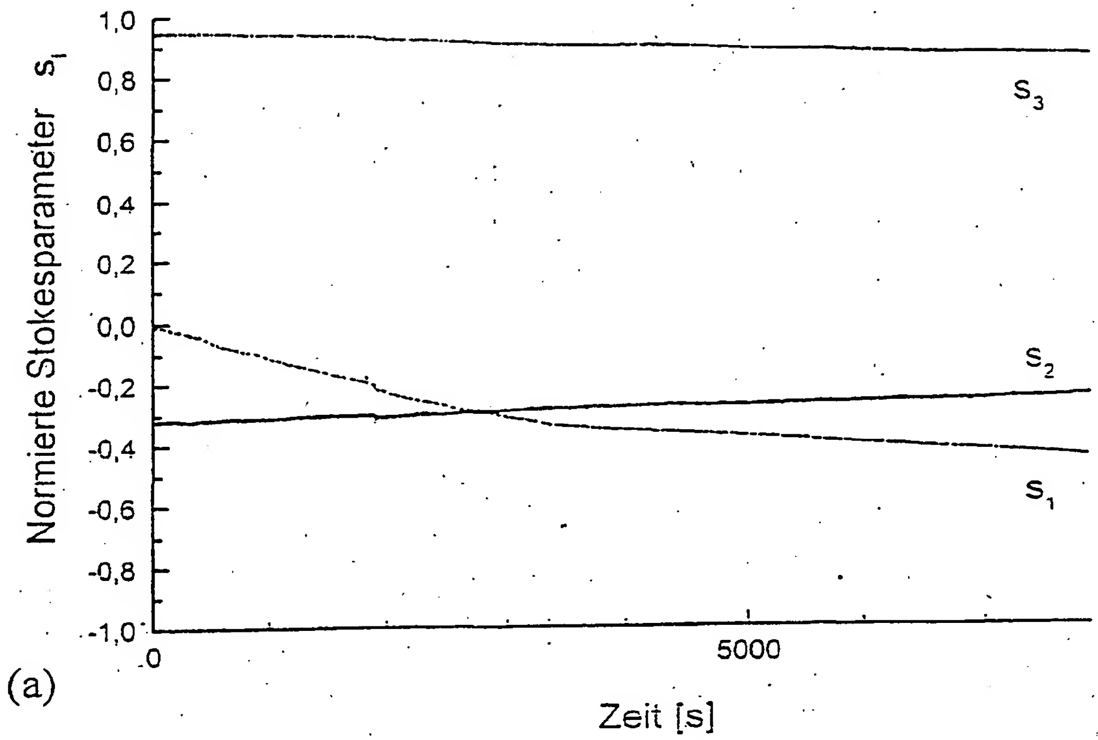


Fig. 3 OTDR-Messungen während des Telekombetriebs



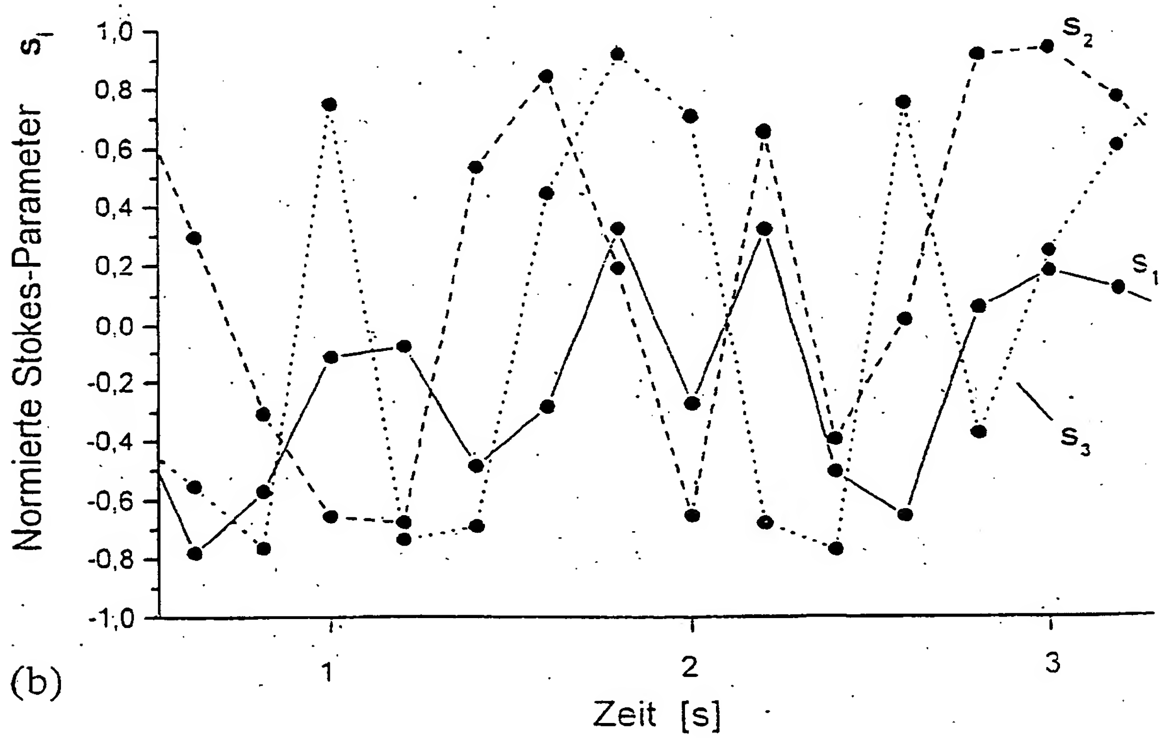


Fig. 4a,b Fluktuationen der Stokes-Parameter einer ungestörten (a) und einer gestörten (b) Faserstrecke

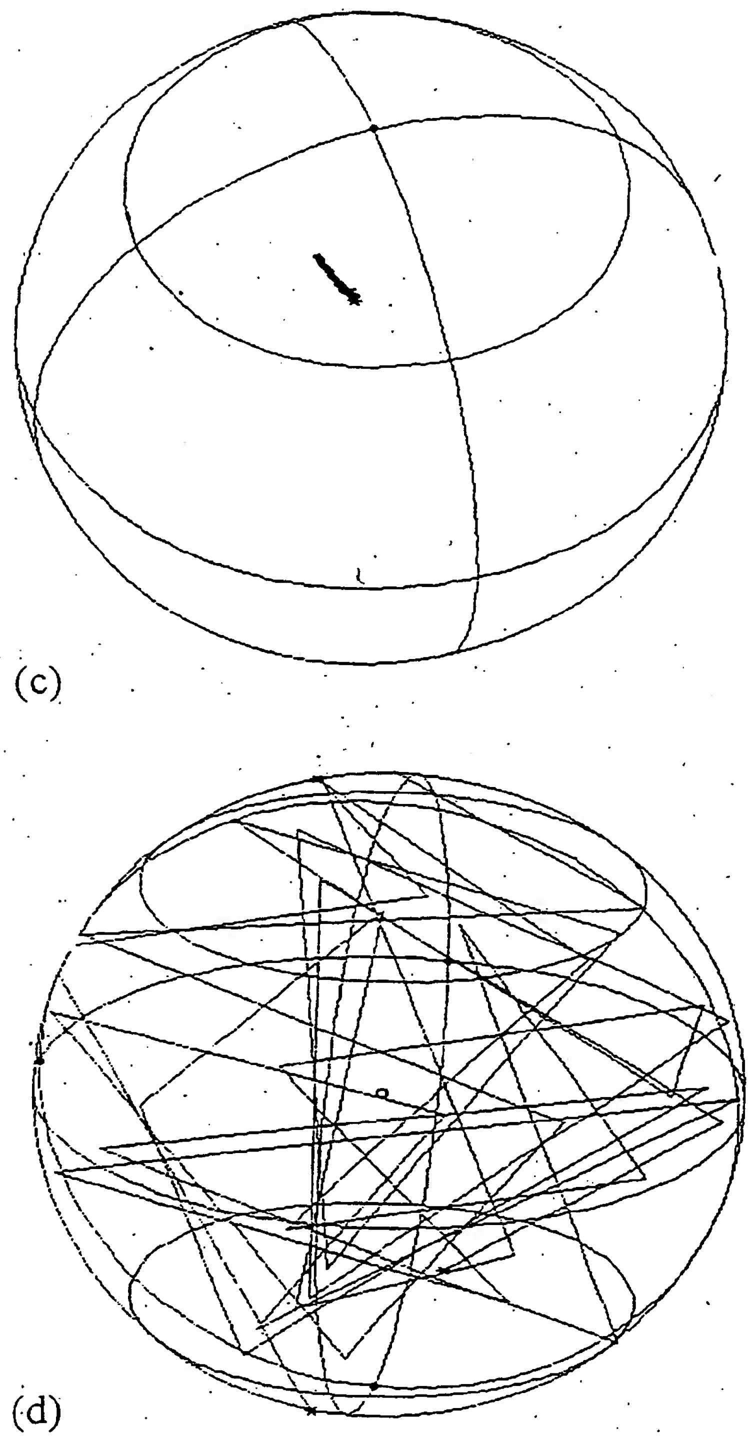
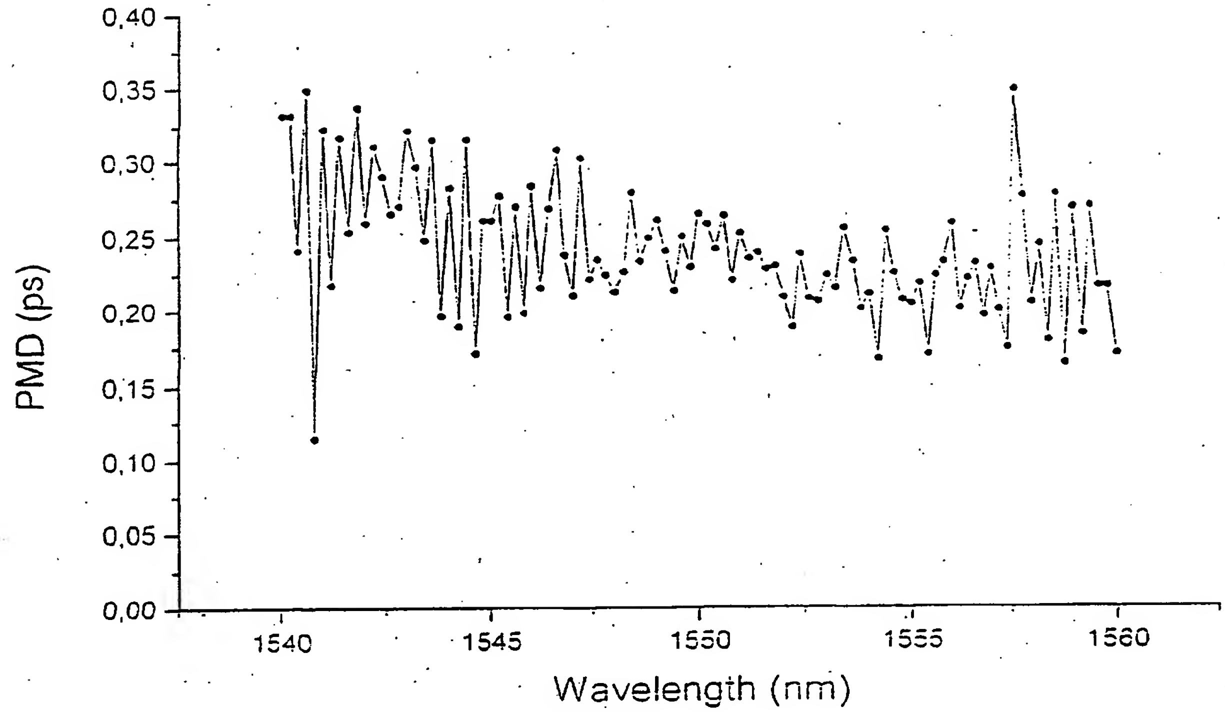


Fig. 4c,d Spuren auf der Poincarekugel
(c) ungestörter Zustand (d) im Störungsfalle



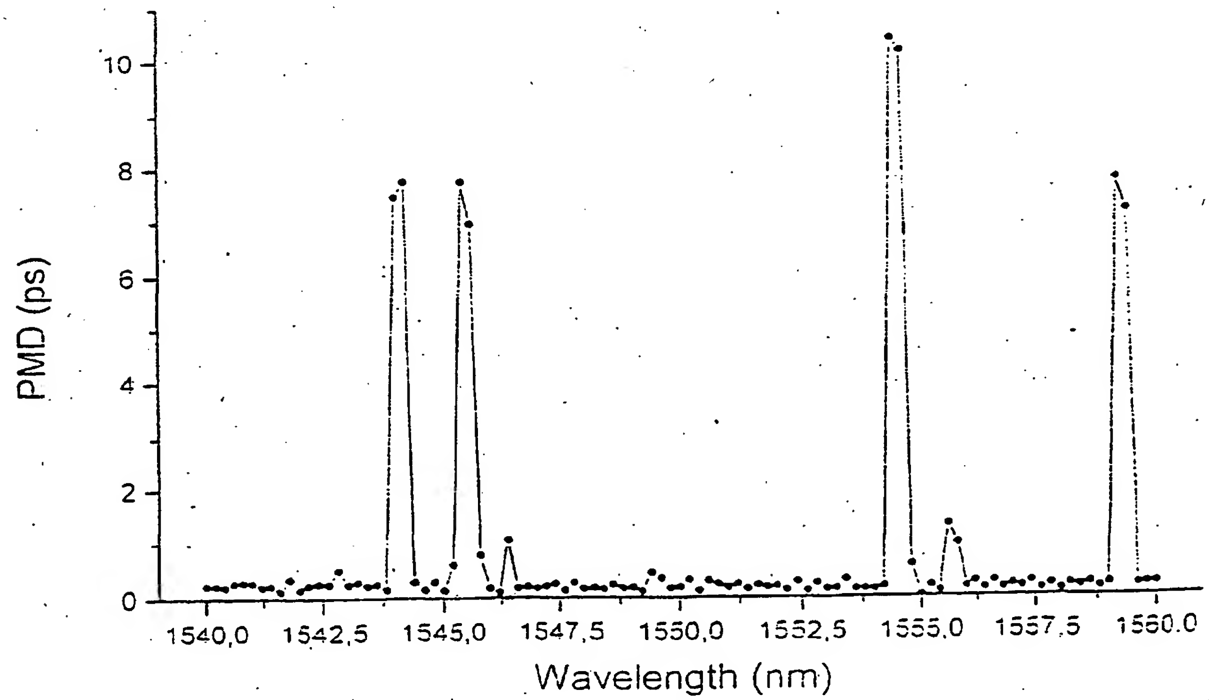


Fig. 5 PMD-Spektrum einer Fiberware-Faser auf einer Spule (L=23.13km) zwischen 1540 und 1560nm ohne (oben) und mit Störungen (unten), gemessen mit dem Polarimeter im Arc-Angle-Modus, $\Delta\lambda$=0.2nm

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(54) **Optical fiber link control safety system.**

(57) A fully redundant safety interlock system is provided comprising, means for detecting the loss of light on a fiber optic link; controller means, coupled to said means for detecting, for determining the safety condition of the link based on the output of said means for detecting, and for controlling the radiant energy output of an optical transmitter, based on the determined safety condition, via redundant output control signals; and means, coupled to said controller means, responsive to said redundant control signals, for interconnecting the output of said controller means to transmitter drive circuitry to thereby adjust the radiant energy output by the transmitter. According to a preferred embodiment of the invention, the controller means includes an electronic implementation of two independent state machines, each of which redundantly determines the connection state of the optical link between two optical link cards. The output from the state machines is used to adjust (for example, turn on and turn off) the drive circuitry for the transmitter via fully redundant paths which carry the redundant control signals.

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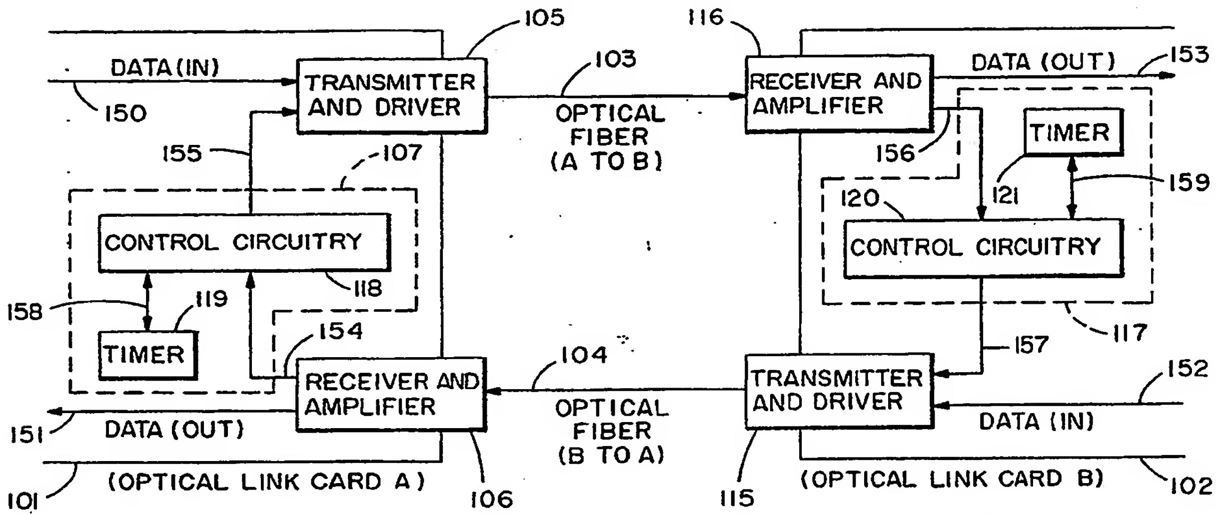
FIG. I



105
116
DATA (IN)
TRANSMITTER AND DRIVER
103
RECEIVER AND AMPLIFIER
DATA (OUT)
153
150
OPTICAL FIBER (A TO B)
TIMER
155
107
156
159
120
121
CONTROL CIRCUITRY
CONTROL CIRCUITRY
118
158
119
117
154
TIMER
104
157
152
RECEIVER AND AMPLIFIER
TRANSMITTER AND DRIVER
OPTICAL FIBER (B TO A)
DATA (IN)
151
DATA (OUT)
101
(OPTICAL LINK CARD A)
106
115
(OPTICAL LINK CARD B)
102

OPTICAL FIBER LINK CONTROL SAFETY SYSTEM

The invention relates generally to safety systems that limit the amount of radiant energy that can be emitted from an open optical fiber or a transmitter port in an optical communication link. More particularly, the invention relates to a safety system that can be incorporated on laser based optical fiber link cards, where the safety system is operative to detect open link failures (for example, an optical fiber in the link which has been disconnected or broken), to reduce the laser's radiant energy output (or shut it off) when an open link failure is detected, to periodically check to determine if the failure is corrected, and to restore full continuous power to the laser upon determining that the link is operationally safe.

Many types of laser based devices and systems, having a wide range of applications, such as in medical technology, in communications and computing technology, etc., are becoming increasingly well known and commercially available.

The lasers used in many of these devices and systems are often capable of producing powerful outputs that are potentially harmful to both people and equipment. As a result, many types of safety devices for use in conjunction with laser based equipment, and standards designed to ensure that laser based equipment may be safely operated, have been developed and continue to evolve.

For example, U.S-A No. 4.423.726, to Imagawa et al, describes a safety device for a laser ray guide (used in the performance of laser surgery) that employs the combination of a lense and a laser ray receiving element, to detect a failure of the laser ray guide. Reflected laser light is used to operate the Imagawa, et al safety system. Although suitable for detecting failures in the local laser based system in which it is used, Imagawa et al does not teach a safety system that controls the laser; does not teach a safety system that shuts the laser down (or limits its power output) upon detecting a failure; and does not teach a safety system suitable for use in performing safety control over long distances, such as over fiber optic links used in communication and/or computing systems.

Safety systems employing reflection to detect fiber failures are both impractical and far too complex (i.e., large and costly) to be used with optical data communication systems because of the difficulty of being able to distinguish the reflection due to a link failure at any point along the link from the reflections due to connectors, splices and the receiver/detector at the end of the link.

Another example of a prior art safety device for a laser based system is taught in U.S-A No. 4.543.477, to Doi et al. This safety system is used to detect problems in an optical transmission fiber of a medical laser application. The system utilizes reflected laser light to control a shutter mechanism which blocks the light when a problem is detected.

Like Imagawa et al, Doi et al does not teach a safety system that controls the laser; does not teach a system that shuts the laser down upon detecting a failure; and does not teach a system that is suitable for performing long distance safety control since reflection is again used as the means for detecting a problem.

In another patent issued to Doi et al, U.S-A No. 4.716.288, a security device is described that detects failures in the transmitting fiber. The application is a high power medical laser used to perform surgery, and features means for detecting fiber damage (using reflection), which disables the laser (to prevent over heating the fiber) when a failure is detected. Although capable of disabling a laser, the Doi et al safety system taught in the U.S-A 4.716.288 patent, like its predecessor in the U.S-A 4.543.477 patent, still uses reflection to detect safety problems and therefore is not a system which is suitable for long distance applications.

Yet another example of a prior art safety system is the high power optical fiber failure detection system taught by Ortiz, Jr., in U.S-A No. 4.812.641. The Ortiz, Jr. safety system is used in equipment that employs a high power pulsed laser to perform material processing. A break or leak in an optical fiber transmitting high power laser energy can be detected by the system, which then shuts down the laser beam delivery system when the optical fiber begins to fail. Separate sensing fibers and detectors are used by the system to detect breaks or leaks in the transmitting fiber.

The use of the separate sensing fibers and detectors called for by Ortiz, Jr., would be especially costly and problematic for long distance safety control applications. The need for the additional fiber links and sensing devices, and the necessity for the additional fibers to span long distances, etc., make such a system unsuitable for use in conjunction with many fiber optic links.

All of the above referenced patents deal with the transmission of power over very short lengths (less than a few meters) of optical fiber in which any failures in the fiber link would cause a substantial change in the reflected power (typically an increase in reflectance) and would create both an exposure and a fire hazard. In contrast, a data communications link operates at much lower power levels and over much longer distances (for example, two kilometers would not be unusual) and a failure in the optical link (for example, a discon-

nected mechanical splice) would create only a viewing hazard and very little change in the amount of reflected power. The impracticality of using reflection combined with the vastly different environments of the current application versus the applications discussed in the referenced patents would make a totally new type of safety control system desirable.

In addition to being able to detect failures in laser based systems and effectively turn a laser off when a fault is detected; it is also desirable in many applications to be able to power the laser back up and resume operations after the condition causing the fault has been corrected.

No safety control systems are known that combine a link failure detection capability, that easily and cost effectively detects link failures over the distances spanned by a particular link, with a control system that is capable of reducing the laser's radiant energy output to a safe level (or shutting laser off) when a failure is detected. Additionally, no safety control systems are known that are also capable of periodically checking to determine if a detected failure is corrected, and causing full continuous power to the laser to be restored upon determining that the link is operationally safe.

With the increasing use of fiber optic technology to provide solutions to performance and packaging problems associated with present day computer interconnect applications, communication applications, etc., small laser based feature cards, such as the optical fiber link card described in the European patent application n° 90480198.2 (inventors : L.W. Freitag, G.M. Heiling, S.C. Holter, D.L. Karst and al), entitled : "Optical fiber link card", and filed concurrently with the present invention, are being developed.

From a safety and product certification point of view, it would be desirable if a safety system could be provided that would make each individual card, such as the card described in the above referenced copending patent application, "fail safe", i.e. certifiably safe at other than a total system level.

Many countries require certification of the "product" with respect to laser light emissions. Prior art laser based optical link subassemblies have a dependency on the "box" they are in to maintain compliance. If a safety system could be devised that could be self contained on each card, then the card would become the "product" that needs to be certified; not all the different models of the boxes that it is used in.

The laser safety standards and certifications referred to hereinabove can be very stringent for an open fiber in an optical communication link. For example, the European IEC laser safety standards for class 1 operation limit the amount of power that can be emitted from an open fiber to a maximum level of approximately -8 dBm, which is far below the design point for optimal performance of the link to which the card in the referenced copending patent application is coupled.

In view of the present and evolving standards applicable to laser based optical fiber link systems, including optical fiber link cards, etc., it would be desirable to be able to reduce the certification requirements for such systems as a whole by providing the aforementioned "fail safe" capability at the feature card level. Any safety control system that could provided such a feature would have to be compact enough to fit on an individual card, would need to be compatible with other components on the card (in terms of power requirements, noise, etc.), and would need to be easily and cost effectively operable independent of the length of the fiber link to which the laser on board the card is coupled.

Accordingly, it would be desirable if a safety control system could be provided that (1) operates, in a self contained fashion, as part of an optical fiber link card designed to be coupled to an optical fiber link; (2) operates in cooperation with an identical safety system on the other card included in a bidirectional optical fiber link; (3) provides sufficient safety features to allow the card to conform to all existing worldwide safety regulations for class 1 operation, and to remain class 1 under a single fault condition (class 1 is defined herein as in the International Electrotechnical Commission (IEC) Standard publication number 825, published in 1984); (4) easily and cost effectively detects link failures (such as a disconnected mechanical splice), over the distances spanned by a particular link; (5) reduces (or shuts off) the laser's radiant energy output, when a link failure is detected; (6) periodically checks to determine if the failure is corrected; and (7) restores full continuous power to the laser upon determining that the link is operationally safe.

It is an object of the invention to provide an optical fiber link control safety system that can be self containedon individual laser based optical fiber link cards to thereby allow individual cards to be certified as meeting laser safety standards.

It is a further object of the invention to provide an optical fiber link control safety system that is particularly well suited for inclusion on cooperating optical fiber link cards used for bidirectional optical data communication over a fiber optic link.

It is a particular object of the invention to provide an optical fiber link control safety system that provides sufficient safety features to allow a card on which it is included to conform to all existing worldwide safety regulations for class 1 operation, and to remain class 1 under a single fault condition in the safety system itself.

Further yet, it is an object of the invention to provide an optical fiber link control safety system that easily and cost effectively detects link failures over the distances spanned by a particular link, reduces (or shuts off) the laser's radiant energy output, when a link failure is detected, periodically checks to determine if the failure is corrected; and restores full continuous power to the laser upon determining that the link is operationally safe.

According to a preferred embodiment of the invention, a fully redundant safety interlock system is provided comprising, means for detecting the loss of light on a fiber optic link; controller means, coupled to said means for detecting, for determining the safety condition of the link based on the output of said means for detecting, and for controlling the radiant energy output of an optical transmitter, based on the determined safety condition, via redundant output control signals; and means, coupled to said controller means, responsive to said redundant control signals, for interconnecting the output of said controller means to transmitter drive circuitry to thereby adjust the radiant energy output by the transmitter.

Furthermore, according to a preferred embodiment of the invention, the controller means includes an electronic implementation of two independent state machines, each of which redundantly determines the connection state of the optical link between two optical link cards. The output from the state machines is used to adjust (for example, turn on and turn off) the drive circuitry for the transmitter via fully redundant paths which carry the redundant control signals.

Further yet, according to a preferred embodiment of the invention, the state machines can exist in any one of four states: (1) a "check" state for the inactive mode of the transmitter (e.g., when the transmitter is off or below the class 1 level for radiant energy output); (2) an "active" state for the active (or normal) mode of the transmitter (e.g., where the transmitter is on continuously); (3) a "stop" state; and (4) a "connect" state. States 3 and 4 exist during a sequence of events in which the transmitter can be switched from the inactive mode to the active mode through a third mode, referred to hereinafter as a connect mode.

The invention features performance capabilities in line with the above stated objectives. Furthermore, the invention is compact, operates with the same power supply as the card on which it is mounted, and features a non-defeatable safety interlock which assures that both cards on a bidirectional link include the safety system before delivering continuous full power to a laser.

These and other objects and features of the present invention and the manner of obtaining them will become apparent to those skilled in the art, and the invention itself will be best understood by reference to the following detailed description read in conjunction with the accompanying Drawing.

FIG. 1 is a block diagram which depicts an exemplary optical fiber link between two optical fiber link cards, where each card includes a safety system fabricated in accordance with the teachings of the invention.

FIG. 2 is a block diagram of a preferred embodiment of a fully redundant optical link safety system fabricated in accordance with the teachings of the invention.

FIG. 3 depicts the power launched into the fiber of a bidirectional fiber link during each of the aforementioned three modes of an optical transmitter.

FIG. 4 illustrates schematically how the novel optical link safety system can be inserted onto an optical link card to provide a safety path between the optical transmitter and optical receiver located on each such card.

FIG. 5 is a block diagram of the open fiber link controller depicted in FIG. 4.

FIG. 6 is a block diagram that depicts all states and transitions of each of the state machines that, according to a preferred embodiment of the invention, is incorporated into the open fiber link controller depicted in FIGS. 4 and 5.

FIG. 1 is a block diagram which depicts an exemplary optical fiber link communication system in which the invention can be used. The depicted system includes two identical optical link cards, 101 and 102, coupled by optical fibers 103 and 104.

Card 101 is shown to include a transmitter and driver circuitry (shown combined in FIG. 1 as unit 105), a receiver and an amplifier (shown combined in FIG. 1 as unit 106) and the novel safety system, shown as unit 107. Safety system 107 is shown inserted in the path between unit 105 and unit 106 in the manner contemplated by a preferred embodiment of the invention.

Identical card 102 is also shown to include a transmitter and driver circuitry (shown combined in FIG. 1 as unit 115), a receiver and an amplifier (shown combined in FIG. 1 as unit 116), and safety system 117 coupled therebetween.

Each of the safety systems depicted is further shown to include control circuitry and timer means, labeled as control circuitry 118 and timer means 119 in safety system 107, and as control circuitry 120 and timer means 121 in safety system 117.

FIG. 1 also depicts data input and output links 150 and 151 (for card 101); data input and output links 152 and 153 (for card 102); links 154 through 157, for integrating safety systems 107 and 117 onto cards 101 and 102 respectively; and links 158 and 159, which serve as bidirectional links between

the control circuitry and the timers in each of the safety systems.

A suitable optical link card for inclusion in a communication system such as the one depicted in FIG. 1, is described in The European patent application n° 90480198.2 previously incorporated herein by reference. The incorporated application describes in detail all elements of the system depicted in FIG. 1, except for the details of a safety system (referred to in the incorporated application as the optical fiber control (OFC) circuitry).

It should be noted that units 107 and 117 each contain portions of the deserializer (in particular the transition detector) described in the copending patent application. The purpose of this device and how it cooperates with the safety system described herein, will become apparent hereinafter with reference to the description of a preferred means for detecting loss of light in the optical fiber link.

The novel safety system being described herein is explained in the context of its use in conjunction with the type of card described in the incorporated copending application. The novel safety system is actually physically located on the card in a preferred embodiment described in the referenced application. However, those skilled in the art will recognize that describing the instant safety system in relation to such a card, is done for the sake of illustration only. Such description is not intended to limit the scope of this invention which can be used in conjunction with other optical link cards (on or off card), such as cards that have different power plane structures, different overall sizes, shapes and combinations of components.

Further, for the sake of illustration only, the integrated transmitter and drivers (shown as units 105 and 115 in FIG. 1) will be assumed to be laser based, although other types of optical transmitters could conceivably be controlled by the safety system described herein.

Referring again to FIG. 1, the sequence of events which, according to the invention, are to occur after a disconnection in the optical data link, are set forth immediately hereinafter.

If data link 103 becomes disconnected (for example, a connector is separated or the fiber is cut), unit 116 (on card 102) will signal a loss of light to control circuitry 120 in safety system 117 (also on card 102).

Control circuitry 120 turns off the laser in unit 115 (on card 102) and starts timer 121. Since the laser in unit 115 is now off, a Loss of Light signal will be generated at unit 106 at card 101.

In response, control circuitry 118 (on card 101) will then turn off the laser in unit 105 (on card 101), thus creating a safe condition with respect to the opened end of the link (i.e., no laser radiation exposure).

When each laser is turned off, the timer in the control circuitry associated with each laser is started.

After a predetermined time T, the control circuitry on each of the cards will turn their respective lasers on for a brief period of time t in order to check the link status.

If the line is now a closed loop (e.g., data link 103 is reconnected), then a reconnect handshake is to take place between the two cards and the lasers will then return to normal operation. If the link is still open, the reconnect handshake will fail and the lasers will once again be turned off for T seconds before the check will be repeated.

It should be noted that, according to a preferred embodiment of the invention, either the expiring of the timer or receiving an optical signal from the other card will cause an attempt to reconnect. Hence, the turning on and off of the two lasers will automatically be synchronized.

If both data links 103 and 104 were disconnected at the same time, both cards would independently turn off their lasers since a loss-of-light signal would be generated at each receiver. Normal operation could not return until both data links were reconnected and the proper reconnect handshake had taken place between the cards.

The use of timers and turning the lasers back on after a predetermined time period allow the overall system to return to a normal mode of functioning after an accidental or purposeful disconnection/reconnection of one or more of the connectors. If this timing retry mechanism was not implemented, the entire external system would have to be shut-down and restarted in order for the link to once again become operational.

When performing system start-up (for the overall system depicted in FIG. 1) or performing link reconnection, the invention contemplates a handshaking operation to take place between cards 101 and 102. This ensures that the unit at the other end of the optical fiber link is another card that is capable of shutting down in the event of a break in the link. If the other end of the link does not respond to the handshaking, then, according to the invention, the laser will remain inactive (i.e., either no emission or brief pulses every T seconds) and thereby maintain a safe link. Hence, this electronic safety module functions as a safety interlock which has been designed to be not defeatable.

The invention uses a repetitive pulsing technique during the time that a link is open (instead of CW operation) in order to reduce the maximum possible exposure to a value which is below the level set by existing worldwide standards for class 1 operation.

Safety circuitry (not the safety system being described herein) in the serializer module on the

card described in the incorporated copending patent application, controls the laser's drive current and monitors for various electronic faults. The Open Fiber Link Control (OFC) module (corresponding to the safety system being described herein) has the capability to disable the serializer module and its drive circuitry whenever the optical link between two cards, such as cards 101 and 102 of FIG. 1, is open due to a break or disconnection in the fiber link.

In order to guarantee safety even while a single fault may be present, a fully redundant safety interlock system is employed by the invention.

FIG. 2 shows a block diagram of a preferred embodiment of the safety system. A fully redundant optical link safety system is depicted.

Two independent light receivers, 201 and 202, are used to determine the presence of light at detector 210. Each of the receiver's output and the output from a timer (with the two timers, 220 and 221 in FIG. 2, being included in each of timer means 119 and 121 of FIG. 1, to provide redundancy) is fed into two independent state machines. These redundant state machines, shown as machines 203 and 204 in FIG. 2, determine the connection state of the optical link between cards 101 and 102.

In addition, two separate control lines, 215 and 216, of opposite polarity are required in order to activate the laser drive circuits, shown as unit 250, in the serializer module. FIG. 2 indicates that, in accordance with the preferred embodiment of the invention, that the paths through the safety system are fully redundant.

Receiver 201 of FIG. 2, according to a preferred embodiment of the invention, includes the combination of the transition detector referred to in the copending application, together with a digital filter. Receiver 202 of FIG. 2 includes the combination of the DC detector referred to in the copending application, together with a separate digital filter. The function and components of these devices as part of the safety system will be described in detail hereinafter with reference to FIGS. 4 and 5.

Each of state machines 203 and 204 depicted in FIG. 2 are designed, according to the preferred embodiment of the invention, to exist in one of four states; one state for the inactive or check mode of operation where the laser is being pulsed, one state for the active or normal mode of operation where the laser is on continuously, and two states for the connect sequence of events which allow the laser to switch from the inactive to the active modes of operation.

The power launched, in accordance with the teachings of the invention, into the fiber during the three modes in which the laser operates (the inactive, active and connect sequence modes referred to hereinbefore), is displayed in FIG. 3.

The two stage handshake for the connect sequence is used in order to prevent the optical connection of some other piece of hardware which does not have the open fiber link control function on it.

According to an illustrative embodiment of the invention, four time periods are defined and referred to in FIG. 3. Two 3 ms windows during which a light pulse is transmitted; a 7 ms window during which the safety system determines if indeed another card having a safety system is attached to the link; and a 48.8 second windows after which an attempt to power on an inactive laser takes place.

The 3 ms, 7 ms and 48.8 second windows were chosen only to illustrate the principles of the invention. The specific values chosen were for an optical fiber link up to 2 km in length, where the safety system is included in a card such as the one described in the incorporated application, and further wherein the electronics for realizing the safety system are similar to those components to be described hereinafter.

Those skilled in the art will recognize that the length of the "on" pulse (the 3 ms pulse in the illustrative embodiment of the invention) is a function of the optical power required by the overall system, the response time of the laser drive circuitry, and the laser safety standards which are to be met. Factors such as classification level (class 1, class 2, class 3B, etc.); wavelength of laser light; number of pulses during the applicable time base (where time base depends on the standard and class); accessible emission level (AEL) for a single pulse (which depends on the class, wavelength, pulse time "on", and the safety standard); and worst case environmental and life time effects on the laser's power, all would be considered in determining the length of the "on" pulse for a particular system application.

The 48.8 sec "repetition" time window is determined by the same items as the "on" time. (There is a give and take between the two times because the maximum power is related to duty cycle, i.e., "on' time divided by "repetition" time). Another factor in determining the "repetition" window is how long the external system is willing to wait for a reconnect signal to be sent out.

The 7 ms window is a function of control circuit response time and the time it takes for light to travel to the other end of the link and back (the longest path).

Portion A of FIG. 3 depicts the power launched into the fiber during the inactive mode of the laser, i.e., when the system is being initialized, or when the laser has previously been powered down. Here the 3 ms "on" pulse is depicted occurring once

every 48.8 seconds. "SP" in each of portions A, B and C of FIG. 3 is defined as the set point for the power launched into the fiber.

Portion B of FIG. 3 depicts the active mode of the laser, i.e., where continuous power is output by the laser.

Portion C of FIG. 3 depicts the laser's connect sequence mode, which is designed to assure that another card having an appropriate safety system is connected to the far end of the optical fiber link. This sequence prevents the safety interlock from being defeated by a modulated light source.

Portion C of FIG. 3 illustrates that sometime after the fiber is connected (at the end of one of the 48.8 second windows shown in portion A of FIG. 3), the 3 ms "on" pulse is caused to be sent by the safety system on one of the cards. The safety system on this card, as will be demonstrated hereinafter, is designed to check for return light during the 3 ms window.

At the end of the first 3 ms window depicted in portion C of FIG. 3, the laser is turned off. If return light was detected during the first 3 ms window, then the 7 ms window begins during which the safety system checks for a loss of return light. This occurrence would indicate that a card having an appropriate safety system is indeed coupled to the other end of the link.

If this event occurs during the 7 ms window, the laser is turned back on for 3 ms at the end of the 7 ms window. If return light is detected at the end of the second 3 ms window depicted in portion C of FIG. 3, the laser, under the control of the safety system on the card, is returned to continuous power.

Should a device not containing the safety system be attached to the far end of the link, the check for return light off during the 7 ms window will fail, and the laser will either return to the inactive mode (portion A of FIG. 3) or remain off indefinitely.

Reference is now made to FIG. 4 which illustrates schematically how to integrate the novel safety system, depicted as open fiber link controller 425 in FIG. 4, with laser control electronics, such as those described in the referenced copending patent application.

Controller 425 is shown inserted in a path between the combination of photodiode 480 and amplifier 499 (corresponding to, for example, unit 106 of FIG. 1), and the combination of serializer 451 (which according to the referenced application includes laser drive circuitry) and laser 450 (corresponding to, for example, unit 105 in FIG. 1).

A redundant laser off switch, transistor 401, is shown gated by an additional pnp transistor, transistor 402. A low level at the input of transistor 402 (carried via -off control link 490) forces laser 450 off. The normal "laser on" line of serializer 451 (with the serializer described in the referenced application being suitable for use in conjunction with the instant invention), is controlled by +off control link 491.

When link 491 is high, laser 450 is forced off. Since a simultaneous high level and low level pair of logic lines is required to activate laser, 450, power supply voltage problems cannot force an accidental laser on command.

FIG. 4 also depicts, two light sensors which are used to provide the aforementioned receiver redundancy. Deserializer 452, coupled to controller 425 via link 498, contains one of the sensors, an envelope detector which, according to the illustrative embodiment of the invention, requires a minimum peak to peak AC voltage frequency above 1 MHz to be activated. Since photodiode 480 is AC coupled to this AC receiver, no DC leakages can activate it.

A second detector has been constructed by adding resistors 437, 468 and 469, capacitor 438, and a transistor, (transistor 403), to the photodiode circuit to sense its average DC current. According to the illustrative embodiment of the invention, at least 10 uamps of photodiode current is required to activate transistor 403.

When no light is present, photodiode 480 conducts less than 1 uamp, thus forcing transistor 403 off and +loss-of-light DC line 475 high.

Photodiode 480 is common to both sensors. However, a failure of the photodiode caused by an increase in its dark current (the only industry reported failure mode) can only activate the DC sensor, not the AC sensor.

According to the invention, both sensors must sense light from photodiode 480, followed by loss of light, before laser 450 is allowed to be activated (where loss of light indicates the existence of functional safety means at the other end of the fiber link).

The external (user) system to which the optical link card (as described in the incorporated patent application) is attached, is required to maintain the power supply within the voltage range 5.0 volts, plus or minus 20%. Within this range, the novel safety system is functional and capable of making the proper decisions concerning the link status.

FIG. 4 also depicts POR (power on reset) link 487. A signal on this link may be used by the safety system, but the safety conditions are not dependent on this signal's presence. Loss of the POR will either prevent any turn on attempts or will result in the two redundant circuits never synchronizing. If they do not synchronize, then the two redundant "laser on" signals will be at different times and the laser can never be activated.

The safety system depicted in FIG. 4 is also

shown to include: (1) link 471, which facilitates the output of a link inactive status signal (when appropriate) from controller 425; (2) link 409, which facilitates the output of a laser fault signal; (3) and links 472-474 which facilitates the input of a wrap enable signal, a transmit clock signal, and a forced laser off signal (from a user), respectively.

According to a preferred embodiment of the invention, controller 425 can be implemented in a CMOS gate array packaged in a 28 pin plastic leadless chip carrier (PLCC) module. This module can be contained on the optical link cards described in the incorporated patent application, and can continuously monitor the status of the optical data link to which it is attached. No single fault in the safety system activates a laser such as laser 450.

FIG. 5 depicts a block diagram of controller 425, with only the functional inputs and outputs necessary to describe the invention being shown. Other inputs and outputs (used for test purposes) are not depicted; however, those skilled in the art will readily appreciate that such inputs and outputs are desirable.

To aid in matching the functional inputs and outputs depicted in FIG. 5 with the schematic shown in FIG. 4, certain input and output link reference numerals from FIG. 4 are included in FIG. 5.

The block diagram for controller 425, as depicted in FIG. 5, shows that the controller provides two control paths that must be satisfied before the laser will be activated. This provides the desired redundancy required for optical safety.

Each path is shown to include a digital filter, state machine and a counter. In particular, a first path, between input link 498 and -laser off link 490, is shown to include digital filter 501, state machine 502 and counter 503. The second path, between input link 475 and output +laser off link 491, is shown to include digital filter 504, state machine 505 and counter 506.

Counter 503 is shown coupled to state machine 502 (via links 576 and 577); while counter 506 is shown coupled to state machine 505 (via links 578 and 579), and to clock detector 541 (to be described hereinafter) via link 597.

The internal redundancy (within controller 425) is complimented externally, by the two aforementioned light detectors,and the two "laser off" circuits controlled via links 490 and 491 of FIG. 4.

The two loss of light detectors each feed a digital filter. The output of each filter and active state signal outputs from the respective state machines (fedback via links 520 and 521 in FIG. 5), are used by the "OR/EQL" function blocks (507 and 508 in FIG. 5) to form independent Loss of Light (LOL) signals (on links 511 and 512 in FIG. 5) internal to controller 425.

The "OR/EQL" function block is designed so that whenever the active state line is low (i.e., the state machine is in the check, stop or connect states), then both digital filter signals must agree in order for the LOL output signal to change logic levels. Hence, in the check or connect states, the LOL line will initially be high (LOL = 1) and both digital filter signals must simultaneously indicate light present (logical 0) in order for LOL to switch low (LOL = 0). Similarly, in the stop state, LOL is initially low (LOL = 0) and both filter signals must simultaneously indicate loss of light (logical 1) in order for LOL to switch high (LOL = 1). However, if the state machine is in the active state, a simple "OR" of the outputs of the digital filters is used to form the LOL signal. This allows either light detector, upon detecting a loss of light, to cause the state machine to exit the active state and turn off the laser.

The LOL signals are used to synchronize the counters and state machines. The state machines control the connect sequence implemented on controller 425. A state diagram for these machines is shown in FIG. 6 and will be described in detail hereinafter.

Each state machine (502 and 505) controls a "laser off" output line (490 and 491 respectively) that connect to separate "laser off" circuits. The counters (503 and 506) control the duty cycle of laser pulsing when controller 425 senses an open link. The counters also provide the low frequency sampling clock to the digital filters (via links 590 and 591).

Digital filters 501 and 504 integrate the incoming signals to improve their reliability. The filters sample every 93 usec with a 22 MHz system clock. The filters used in the illustrative embodiment of the invention need a running total of eight counts in order to switch their outputs. Therefore, the minimum acquisition time is 8 x 93 usec or 744 usec, for these filters.

Controller 425 also contains ring oscillator 540 which drives clock detector 541, which monitors the "Xmit Clock" signal input via link 473. If the "Xmit Clock" signal gets stuck high or low, clock detector 541 will turn the laser off. This arrangement provides a back up safety feature to the single clock coming onto the chip. Changes in the clock frequency will cause the pulse duration and pulse repetition time to scale proportionally such that the duty cycle for the laser pulsing is not affected by the change in clock frequency. The illustrative embodiment of the invention is designed so that when and if the input clock speeds up by more than a factor of three, then the pulses will be too short for the laser to come on; if the clock slows down to 3 MHz, then the clock detector will

turn off the laser.

The clock generator, 596 in FIG. 5, generates two nonoverlapping signals from "Xmit clock" signal 473. These two signals are used to clock all memory elements in controller 425.

The laser off and an electronic wrap input (inputs 474 and 472 respectively) are provided for, and can be controlled externally by, a user. Although a user can turn the laser off immediately by command, it cannot turn the laser on. Only controller 425 can activate the laser. If the link was active prior to executing laser off or wrap, then when either laser off or wrap return to their original state, the illustrative embodiment of the invention will immediately send out a 3 ms laser pulse to check the current link status. If the link was inactive prior to executing laser off or wrap, then the 48.8 sec wait period must elapse before the 3 ms laser pulse is sent.

During power-on-reset (POR) situations, controller 425 prevents any exposure to unsafe levels of laser radiation. An attempt to power on the laser is not made until 48.8 seconds after a valid POR is received. Therefore even during the initial power up period, the safety control circuitry is functional.

Finally, FIG. 5 depicts de-glitch circuits 515 and 516 which ensure the stability of the -POR, -wrap enable and +laser off inputs; and other standard logic as specifically indicated in FIG. 5, to gate the various inputs and outputs to/from controller 425.

Reference is now made to FIG. 6 which is a block diagram that depicts all states and transitions of each of the state machines that, according to a preferred embodiment of the invention, is incorporated into the open fiber link controller (controller 425) depicted in FIGS. 4 and 5. Each machine verifies that the card on the other end of the fiber also has open fiber sense circuitry. A description of all the states and transitions follows immediately hereinafter.

Each state machine has four variables that control the transitions from state to state. The Loss of Light (LOL) signal is formed by the aforementioned "OR/EQL" function such that both sensors must agree to pass through check, stop and connect states to activate the link, but once activated either light sensor detecting no light will stop the link.

The three decodes (shown in the key on FIG. 6 as D1, D2 and D3) are generated by each counter in controller 425. The decodes are used to ensure that no ON-OFF-ON sequence generated by the physical insertion of a fiber into the connector can accidentally indicate a safe link. The timing of each decode is based on the illustrative embodiment's 22 MHz clock input. All the timing would change proportionally if the clock frequency is changed.

What follows is a functional description of each of the four states of operation of controller 425. Those skilled in the art can readily implement the desired state machines on controller 425, using off-the-shelf electronic components, once the desired function of each state machine is understood.

The state machine is assumed to start in the "check" state, indicated by block 601 in FIG. 6. While in the check state, controller 425 is checking for a closed optical link by transmitting a 3 ms light pulse every 48.8 seconds. As long as LOL remains high, controller 425 stays in this state. To exit from check state, light must be sent and received by the optical link card. This is satisfied if controller 425 is responding to an incoming pulse or receiving an answer to an outgoing pulse.

If during a 3 ms D1 light pulse transmission (i.e., D1 = 1), LOL goes low (i.e., an answer is received), then controller 425 exits (as indicated by link 651) to the stop state, shown as block 602 in FIG. 6.

The second way to exit from the check state occurs if LOL goes low (LOL = 0) sometime during the 48.8 second wait period. The counters controlling the timing are reset, D1 is set high (D1 = 1) and a 3 ms light pulse is sent out in response to the received light pulse. This also causes controller 425 to exit (via link 651) to the stop state.

While in the stop state, the 7 ms D2 timer period (D2 = 1) begins, and controller 425 turns off the laser to see if the card at the opposite end of the fiber link responds accordingly. This verifies that the other card has the appropriate open fiber safety circuitry. The laser is not turned off (i.e., the D2 = 1 period does not begin) until after the 3 ms D1 pulse has completed. This ensures that the pulse was long enough for the other card to receive the D1 pulse and send an answer to it. Controller 425 stays in the stop state (as indicated by link 652) for as long as LOL is low (i.e., light is being received). This could be for an indefinite period of time.

One possible exit from the stop state (via link 653) is when LOL=1 and D2=1. This occurs when light is no longer being received (LOL=1) within 7 msec of controller 425 turning off the laser. This is the proper response from the card at the other end of the fiber, and controller 425 then proceeds to the connect state, shown as block 603 in FIG. 6.

The other possible exit from the stop state (via link 654) is when LOL=1, D1=0 and D2=0. This results when light is no longer being received after the 7 msec D2 period of controller 425 has elapsed (D2=0). Controller 425 then goes back to the check state and waits for the 48.8 second timing period to elapse before sending out another 3 ms D1 light pulse.

While in the connect state, controller 425

sends out a second 3 ms light pulse (D3) to establish a verified safe link with the card at the opposite end of the fiber link. The pulse does not get sent out until after the 7 msec D2 period has ended.

Controller 425 will remain in the connect state (as indicated by link 655) during the 3 ms pulse period waiting for an answer to its D3 pulse, D3 = 1 and LOL = 1.

One possible exit (via link 656) from the connect state is when D3 = 1 and LOL = 0. This means the other card answered the D3 pulse. Controller 425 then proceeds to the active state, shown as block 604 in FIG. 6. This is the "proper" response.

The other possible exit (via link 657) from the connect state is when D2 = 0 and D3 = 0. This means the card at the opposite end of the fiber link did not answer within the required 3 ms period. Controller 425 then causes the laser to be turned off, proceeds to the check state, and waits 48.8 seconds before sending out a D1 pulse in another attempt to link up.

Finally, FIG. 6 depicts the active state (block 604). During the active state controller 425 latches the laser on. Controller 425 stays in the active state as long as light is being received, i.e., LOL = 0 as indicated by link 659.

The only exit from the active state (via link 658) is when LOL = 1 (i.e., light is no longer being received). This could be from an open fiber or the other card turning its laser off for any reason. Controller 425 would then proceed to the check state.

Controller 425 is meant to have (and does have) absolute control over the operation of the laser in the event of a break anywhere in the round trip link between itself and another optical link card. Controller 425 makes use of pulsing during the time that a link is open in order not to exceed the class 1 limits for laser radiation exposure while still allowing the link to resume normal operation should the connection once again become closed. In addition, controller 425 makes use of the previously described reconnection handshake to ensure that the card at the other end of the link contains a properly functioning safety system. Thus, controller 425 provides an electronic safety interlock for the optical link card.

What has been described is a safety system meeting all of the objectives set forth hereinbefore. Those skilled in the art will recognize that the foregoing description has been presented for the purposes of illustration and description only. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching.

The embodiments and examples set forth herein were presented in order to best explain the principles of the instant invention and its practical application to thereby enable others skilled in the art to best utilize the instant invention in various embodiments and with various modifications as are suited to the particular use contemplated.

Claims

1. A fully redundant safety interlock for a fiber optic link, comprising :
   (a) means for detecting loss of light on said link, including means for outputting at least two independent Loss of Light signals; and
   (b) controller means, coupled to said means for detecting, for controlling the radiant energy output by an optical transmitter, based at least in part on the values of said independent loss of light signals.

2. Apparatus as set forth in claim 1 wherein said controller means is operative to cause the radiant energy output by said optical transmitter to be limited or shut off whenever said transmitter is continuously outputting radiant energy and any of said Loss of Light signals indicate loss of light on the link.

3. Apparatus as set forth in claim 1 wherein said controller means further comprises :
   (a) means for determining the safety condition of said link, in terms of whether or not the link is closed and contains functioning safety apparatus at the opposite end of the link, including means for outputting at least two separate signals indicative of said safety condition; and
   (b) output means, coupled to said means for determining, for outputting redundant signals in response to said separate signals, wherein said redundant signals may be used to control the radiant energy output by said transmitter,

   and wherein said means for determining further comprises a plurality of state machines, the states of which are used, together with said independent Loss of Light signals, to determine the safety condition of said link, and said means for detecting further comprises a plurality of timers, each associated associated with one of said plurality of state machines.

4. Apparatus as set forth in claim 3 further comprising interconnect means, coupled to said output means, for interconnecting said redundant signals to transmitter drive circuitry, and wherein said interconnect means comprises a redundant laser switch that requires redundant

signal inputs of opposite polarity to continuously activate said transmitter.

5. Apparatus as set forth in any one of claims 1 to 4 wherein said means for detecting further comprises at least two independent light sensors, at least one of said light sensors being an AC coupled light detector and at least one of said light sensors being a DC coupled light detector.

6. Apparatus as set forth in any one of claims 1 to 5 wherein said controller means further comprises means for powering down said transmitter in response to user input control signals.

7. Apparatus as set forth in any one of claims 1 to 6 wherein said controller means further comprises means for signalling inactive link status to a user.

8. Apparatus as set forth in any one of claims 1 to 7 wherein said controller means is responsive to user generated power on reset signals and, in response thereto, first determines the safety condition of said link before permitting the transmitter to be continuously activated.

9. Apparatus as set forth in any one of claims 3 to 8 wherein said state machines each include at least a check state, corresponding to an inactive mode of said transmitter; an active state, corresponding to an active mode of said transmitter; and both a stop state and a connect state, which exist when said transmitter is in a connect mode.

10. Apparatus as set forth in claim 9 wherein the redundant signals output by said controller means are operative to cause said transmitter to be pulsed at a predetermined frequency during said inactive mode.

11. Apparatus as set forth in claim 9 wherein the redundant signals output by said controller means are operative to cause reconnection handshake signals to be output by said transmitter during said connect mode, to enable said controller means to determine if said link is closed and that functioning safety apparatus exists at the opposite end of the link, and wherein said redundant signals output by said controller means are operative to inhibit continuous power from being provided to said transmitter unless said controller means determines during said connect mode that said link is closed and contains functioning safety apparatus at the opposite end of the link.

12. Apparatus as set forth in claim 9 wherein the redundant signals output by said controller means are operative to provide continuous power to said transmitter during said active mode.

13. A fully redundant safety interlock for a fiber optic link, comprising :

(a) means for sensing a fiber disconnect as a function of at least two independent signals which each indicate the presence or absence of light on said link;

(b) controller means, coupled to said means for sensing, operative to cause the radiant energy output by an optical transmitter to be limited or shut off whenever a fiber disconnect is sensed.

14. Apparatus as set forth in claim 13 wherein said controller means further comprises means for periodically causing said transmitter to emit pulses used to determine if said fiber has been reconnected, wherein said controller means further comprises means for causing reconnect handshake signals to be output by said transmitter, to enable said controllers means to determine if said link is closed and that functioning safety apparatus exists at the opposite end of the link, and wherein said controller means further comprises means for causing the restoration of continuous radiant energy output by said transmitter whenever said fiber has been reconnected, so long as said reconnect handshake signals indicate that functioning safety apparatus exists at the opposite end of the link.

15. An open fiber link safety system for providing a fully redundant safety interlock for a fiber optic link, wherein said link includes first and second optical link cards, each of which is capable of transmitting and receiving data over said link, and further wherein said first card includes a first optical transmitter, driver means for said first transmitter, and first receiver/amplifier means; and further wherein said second card includes a second optical transmitter, driver means for said second transmitter, and second receiver/amplifier means, comprising :

(a) first safety means, coupled between said driver means for said first optical transmitter and said first receiver/amplifier means;

(b) second safety means, coupled between said driver means for said second optical transmitter and said second

receiver/amplifier means; wherein said first and second safety means are each operative to power down the respective transmitters to which they are coupled upon detecting a break in said link.

16. Apparatus as set forth in claim 15 wherein each of said safety means further comprises;
(a) means for detecting loss of light on said link, including means for outputting at least two independent Loss of Light signals; and
(b) controller means, coupled to said means for detecting, for controlling the radiant energy output by an optical transmitter, based at least in part on the values of said independent loss of light signals,
each of said safety means being further operative to cause continuous radiant energy output by said first and second optical-transmitters, when a link is being initialized or reconnected, only if each safety means is able to verify the existence of the other safety means as part of the link, and
each of said controller means further comprising :
(a) means for determining the safety condition of said link, in terms of whether or not the link is closed and contains functioning safety apparatus at the opposite end of the link, including means for outputting at least two separate signals indicative of said safety condition; and
(b) output means, coupled to said means for determining, for outputting redundant signals in response to said separate signals, wherein said redundant signals may be used to control the radiant energy output by said transmitter.

17. Apparatus as set forth in claim 16 wherein said means for determining further comprises a plurality of state machines, the states of which are used, together with said independent Loss of Light signals, to determine the safety condition of said link, and wherein said means for detecting further comprises a plurality of timers, each associated with one of said plurality of state machines.

18. A method for providing a fully redundant safety interlock for a fiber optic link, wherein said link includes a first optical fiber, a second optical fiber, first and second optical link cards, each of which is capable of transmitting and receiving data over said link, and further wherein said first card includes a first optical transmitter for transmitting optical signals between said first card and said second card via said first fiber, first receiver/amplifier means, first safety control means and first timer means; and further wherein said second card includes a second optical transmitter for transmitting optical signals between said second card and said first card via said second fiber, second receiver/amplifier means, second safety control means and second timer means, comprising the steps of:
(a) disabling said first and second optical transmit ters whenever said first optical fiber is discon nected by :
(a1) generating a first Loss of Light signal via said second receiver/amplifier means, for use by said second safety control means whenever said first fiber is disconnected from the link;
(a2) powering down said second optical transmitter, via said second safety control means, in response to said first Loss of Light signal;
(a3) starting a timer, maintained by said second timer means, via said second safety control means;
(a4) generating a second Loss of Light signal, via said first receiver/amplifier means, as a result of said second optical transmitter being powered down; and
(a5) powering down said first optical transmit ter, via said first safety control means, in response to said second loss of light signal, to thereby create a safe condition with respect to the open link created by the disconnection of said first optical fiber;
(b) starting a timer, maintained by said second timer means, when said second optical transmitter is powered down according to step (a2);
(c) starting a timer, maintained by said first timer means, when said first optical transmitter is powered down according to step (a5); and
(d) powering up each of said first and second optical transmitters after a time period T, for a smaller time period t, in a synchronous fashion, in order to check link status.

19. A method as set forth in claim 18 further comprising the step of generating reconnect handshake signals via said first and second safety control means to verify closed link status and verify that a functioning safety device exists at both ends of the link, the step of permitting continuous radiant energy to be output by both said first and second optical transmitters in the event both closed link status and the existence of a functioning safety device at

both ends of the link are verified via said handshake signals, and the step of powering down said first and second optical transmitters for time period T and repeating step (d) if said handshake signal fails to verify both closed link status and the existence of a functioning safety device at both ends of the link.

20. A method for providing a fully redundant safety interlock for a fiber optic link, wherein said link includes a first optical fiber, a second optical fiber,

first and second optical link cards, each of which is capable of transmitting and receiving data over said link, and further wherein said first card includes a first optical transmitter for transmitting optical signals between said first card and said second card via said first fiber, first receiver/amplifier means, first safety control means and first timer means; and further wherein said second card includes a second optical transmitter for transmitting optical signals between said second card and said first card via said second fiber, second receiver/amplifier means, second safety control means and second timer means, comprising the steps of :

(a) disabling said first and second optical transmitters whenever said second optical fiber is disconnected by :

(a1) generating a first Loss of Light signal via said first receiver/amplifier means, for use by said first safety control means whenever said second fiber is disconnected from the link;

(a2) powering down said first optical transmitter, via said first safety control means, in response to said first Loss of Light signal;

(a3) starting a timer, maintained by said first timer means, via said first safety control means;

(a4) generating a second Loss of Light signal, via said second receiver/amplifier means, as a result of said first optical transmitter being powered down; and

(a5) powering down said second optical transmit ter, via said second safety control means, in response to said second loss of light signal, to thereby create a safe condition with respect to the open link created by the disconnection of said second optical fiber;

(b) starting a timer, maintained by said first timer means, when said first optical transmitter is powered down according to step (a2);

(c) starting a timer, maintained by said second timer means, when said second optical transmitter is powered down according to step (a5); and

(d) powering up each of said first and second optical transmitters after a time period T, for a smaller time period t, in a synchronous fashion, in order to check link status.

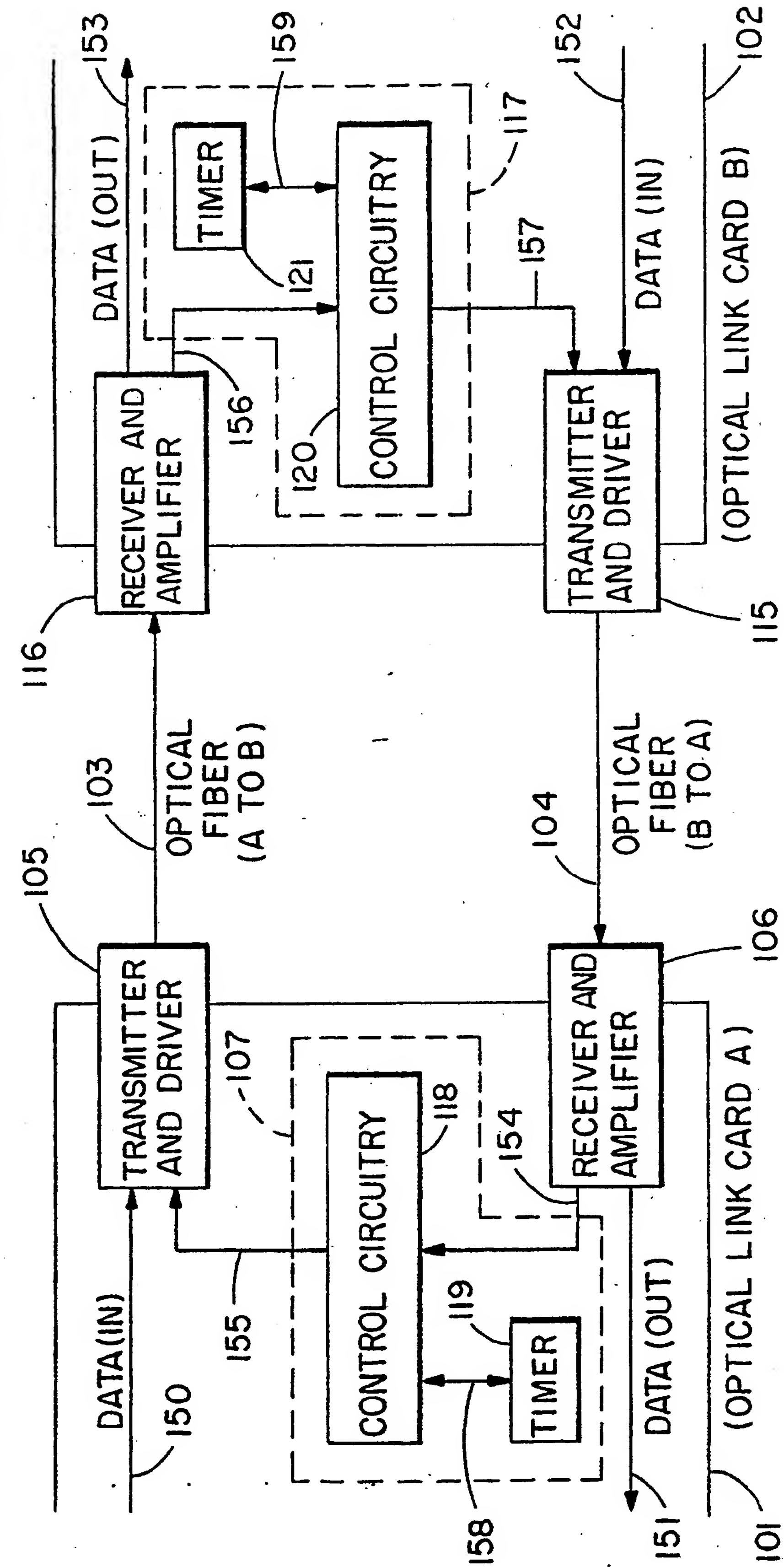

DATA (OUT)
153
159
TIMER
CONTROL CIRCUITRY
117
121
157
156
120
RECEIVER AND AMPLIFIER
TRANSMITTER AND DRIVER
DATA (IN)
152
102
(OPTICAL LINK CARD B)
116
115
OPTICAL FIBER (A TO B)
103
OPTICAL FIBER (B TO A)
104
105
106
TRANSMITTER AND DRIVER
RECEIVER AND AMPLIFIER
107
CONTROL CIRCUITRY
118
154
155
119
TIMER
DATA(IN)
150
158
DATA (OUT)
151
(OPTICAL LINK CARD A)
101

FIG. I

FIG. 2

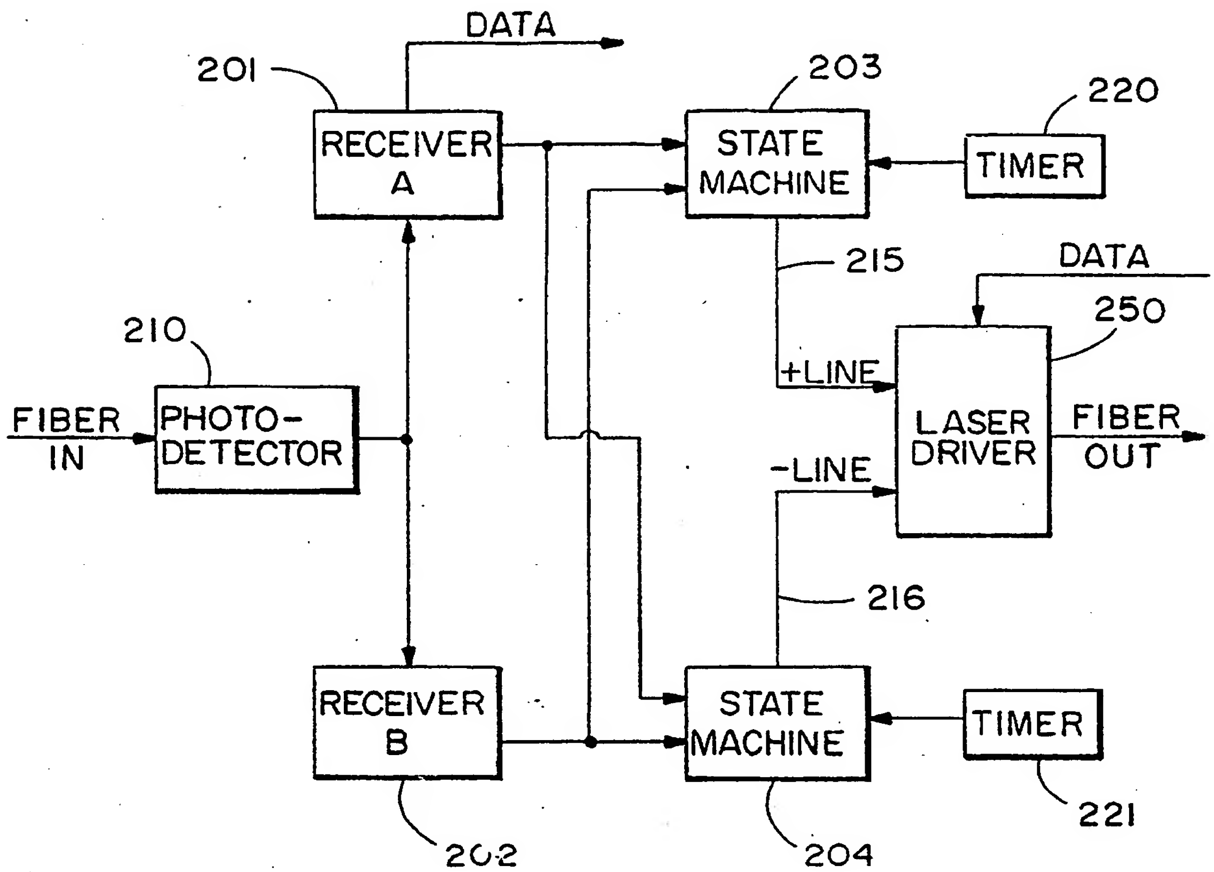
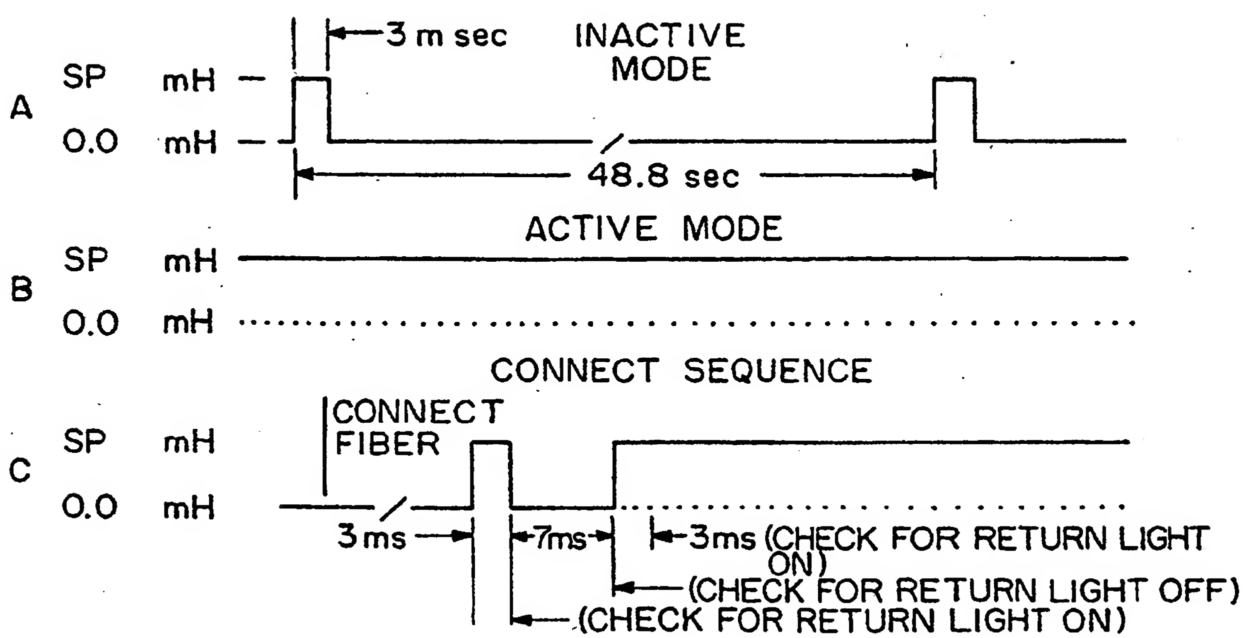

DATA
201
RECEIVER A
203
STATE MACHINE
220
TIMER
215
DATA
250
210
+LINE
FIBER IN
PHOTO-DETECTOR
LASER DRIVER
FIBER OUT
-LINE
216
RECEIVER B
STATE MACHINE
TIMER
221
202
204

FIG. 3


3 m sec
INACTIVE MODE
A
SP mH
0.0 mH
48.8 sec
ACTIVE MODE
B
SP mH
0.0 mH
CONNECT SEQUENCE
C
SP mH
0.0 mH
CONNECT FIBER
3 ms
7ms
3ms (CHECK FOR RETURN LIGHT ON)
(CHECK FOR RETURN LIGHT OFF)
(CHECK FOR RETURN LIGHT ON)

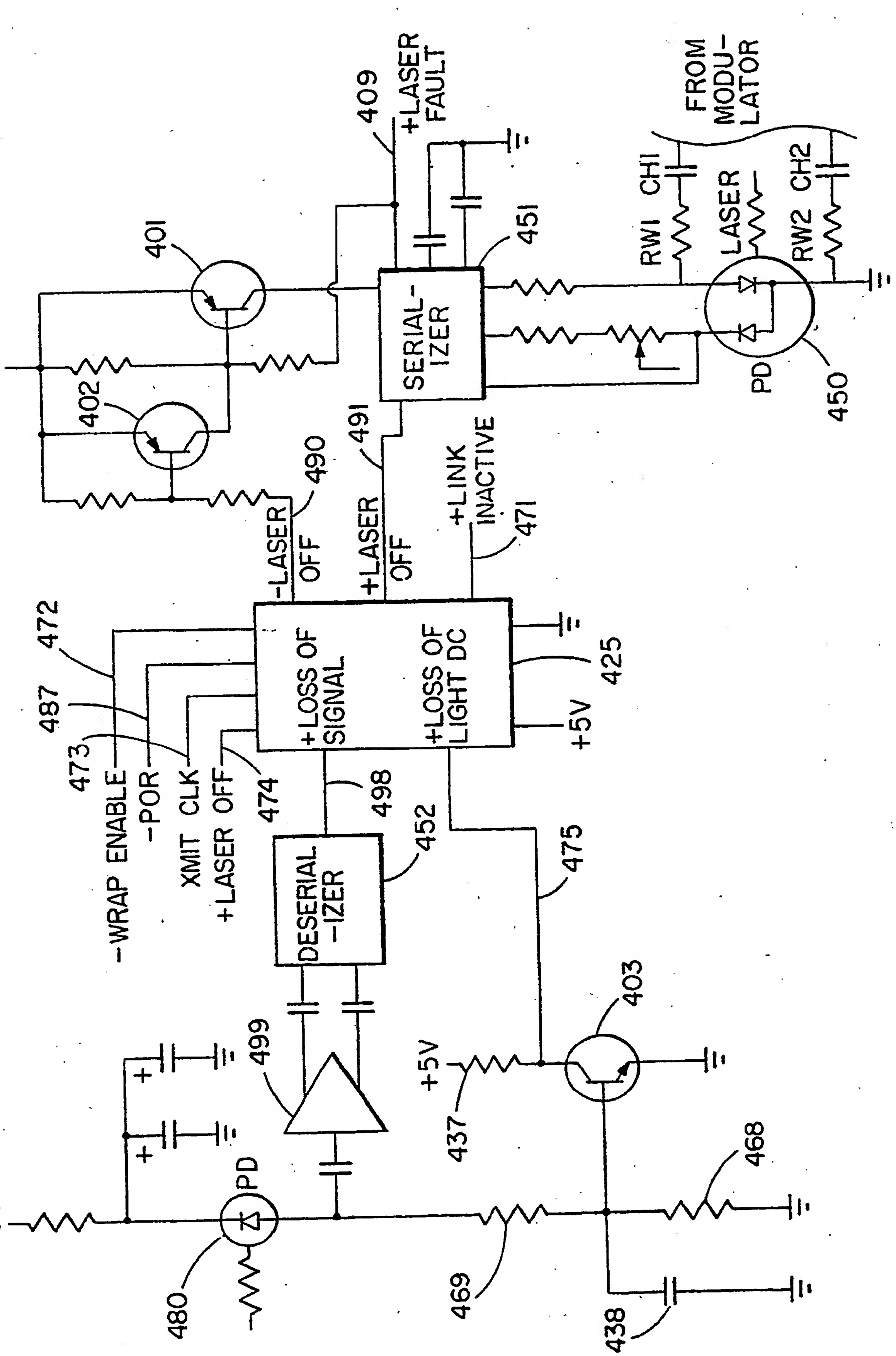

+5V
401
402
409
+LASER FAULT
FROM MODU-LATOR
RW1 CH1
LASER
RW2 CH2
451
SERIAL-IZER
PD
450
490
491
-LASER OFF
+LASER OFF
+LINK INACTIVE
471
472
487
473
474
-WRAP ENABLE
-POR
XMIT CLK
+LASER OFF
+LOSS OF SIGNAL
+LOSS OF LIGHT DC
425
+5V
498
452
DESERIAL-IZER
475
499
403
+5V
437
468
469
438
480
PD
+5V

FIG. 4

FIG. 5

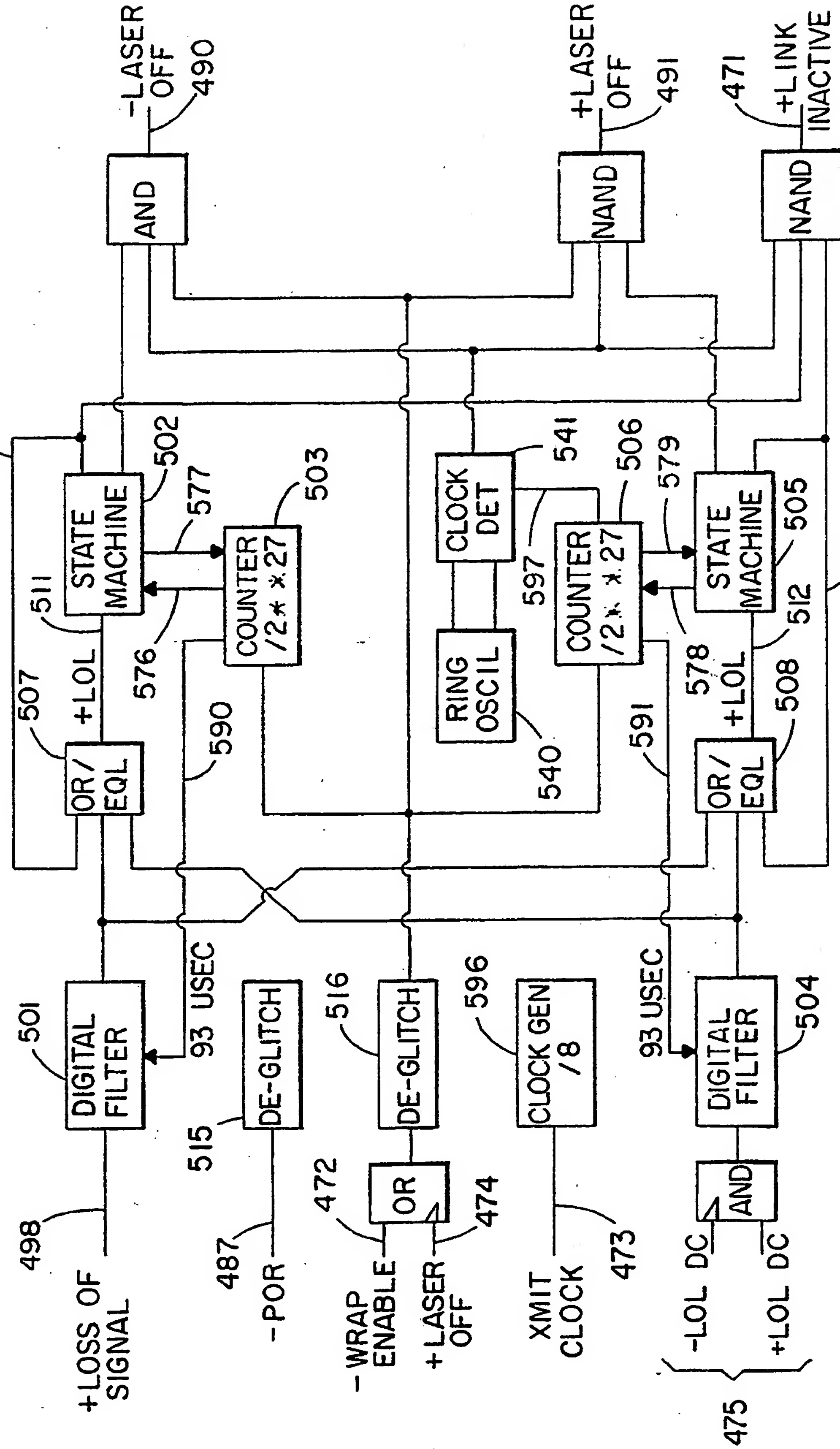
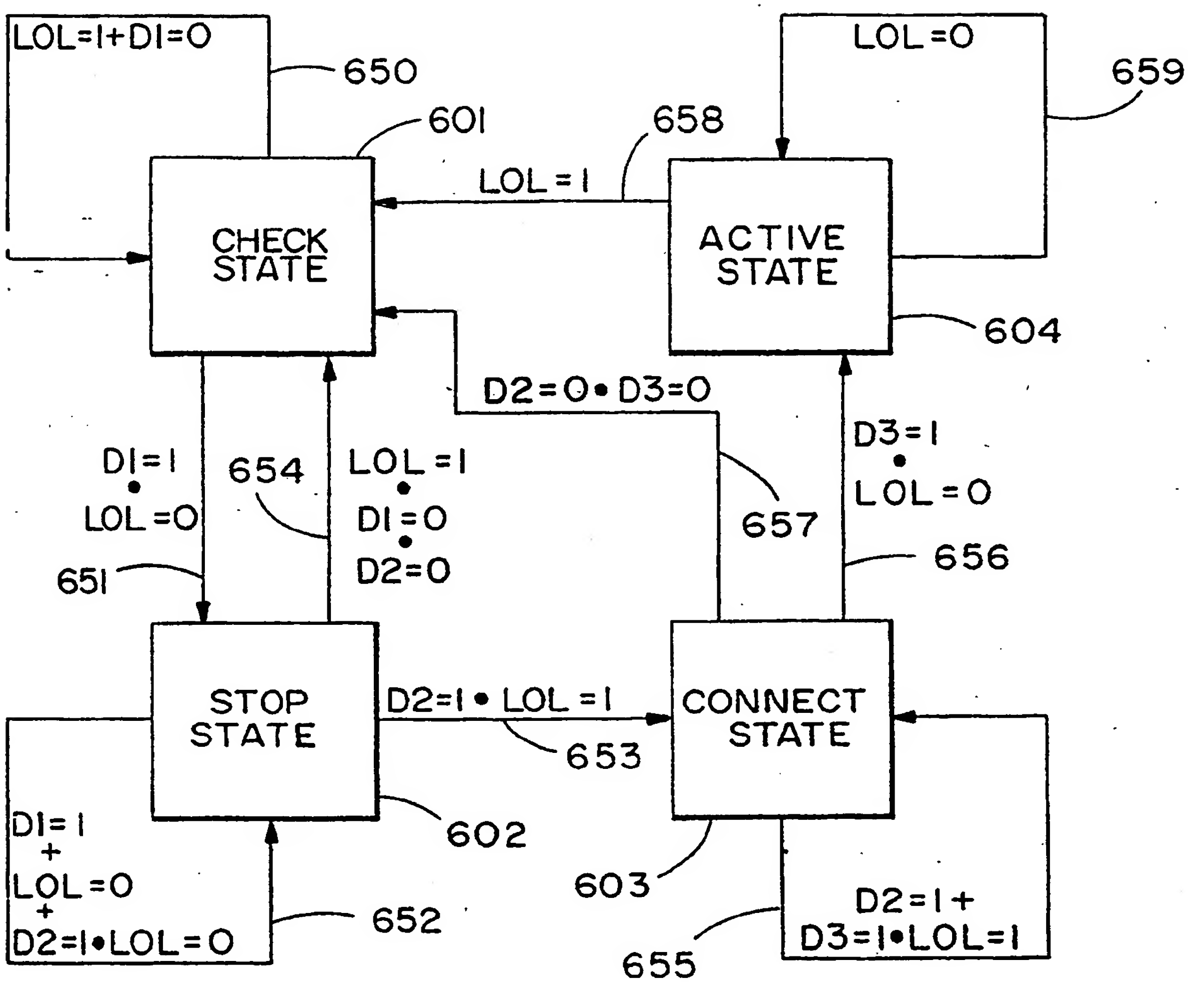

+LOSS OF SIGNAL
498
DIGITAL FILTER
501
93 USEC
-POR
487
DE-GLITCH
515
- WRAP ENABLE
+LASER OFF
472
474
OR
DE-GLITCH
516
XMIT CLOCK
473
CLOCK GEN /8
596
-LOL DC
+LOL DC
475
AND
DIGITAL FILTER
504
93 USEC
OR / EQL
507
+LOL
STATE MACHINE
511
502
576
577
COUNTER /2* *.27
503
590
520
AND
-LASER OFF
490
RING OSCIL
540
CLOCK DET
541
597
COUNTER /2* *.27
506
591
579
578
STATE MACHINE
505
512
+LOL
OR / EQL
508
521
NAND
+LASER OFF
491
NAND
471
+LINK INACTIVE

FIG. 6



KEY

LOL = LOSS OF LIGHT
D1 = DECODE 1 — 1st 3ms LIGHT PULSE
D2 = DECODE 2 — 7ms OFF
D3 = DECODE 3 — 2nd 3ms LIGHT PULSE

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(54) **Optical fiber link control safety system.**

(57) A fully redundant safety interlock system is provided comprising, means for detecting the loss of light on a fiber optic link; controller means, coupled to said means for detecting, for determining the safety condition of the link based on the output of said means for detecting, and for controlling the radiant energy output of an optical transmitter, based on the determined safety condition, via redundant output control signals; and means, coupled to said controller means, responsive to said redundant control signals, for interconnecting the output of said controller means to transmitter drive circuitry to thereby adjust the radiant energy output by the transmitter. According to a preferred embodiment of the invention, the controller means includes an electronic implementation of two independent state machines, each of which redundantly determines the connection state of the optical link between two optical link cards. The output from the state machines is used to adjust (for example, turn on and turn off) the drive circuitry for the transmitter via fully redundant paths which carry the redundant control signals.

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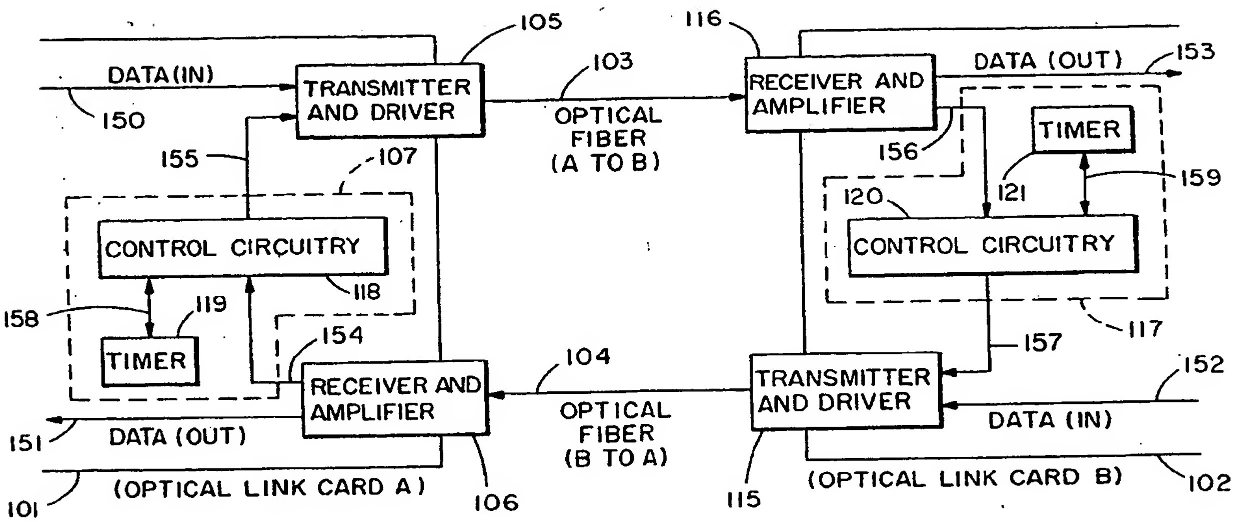
FIG. 1


105
116
103
153
DATA (IN)
TRANSMITTER AND DRIVER
OPTICAL FIBER (A TO B)
RECEIVER AND AMPLIFIER
DATA (OUT)
150
155
107
156
TIMER
159
121
120
CONTROL CIRCUITRY
CONTROL CIRCUITRY
118
117
158
119
154
157
TIMER
104
152
RECEIVER AND AMPLIFIER
TRANSMITTER AND DRIVER
OPTICAL FIBER (B TO A)
DATA (IN)
151
DATA (OUT)
(OPTICAL LINK CARD A)
(OPTICAL LINK CARD B)
102
101
106
115

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 48 0199

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	DE-A-3 147 555 (SIEMENS AG)	1,2,6,7, 13-16	H04B10/08
Y	* the whole document *	8	
A		3,10, 18-20	
P,X	EP-A-0 382 243 (FUJITSU)	1,2,13, 15	
	* column 2, line 30 - column 3, line 31 *		
P,A	* abstract; figures 4,5 *	3,16, 18-20	
Y	PATENT ABSTRACTS OF JAPAN vol. 10, no. 75 (E-390)(2132) 25 March 1986 & JP-A-60 220 633 (NIPPON DENKI)	8	
A	* abstract *	7	
A	GB-A-2 195 508 (STC)	1-3,6, 13-16, 18-20	
	* the whole document *		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12 MARCH 1992	WAGNER U.

CATEGORY OF CITED DOCUMENTS

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